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M.V. KALVIK
PROPULSION SYSTEM FULL SCALE TESTS

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Volume 1 - Final Report

by

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Un sommaire en français de ce document est inclus avant la table des matières.

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PROJECT TEAM

This program has been conducted with the support and on behalf of three contributory participants: the Transportation Development Centre of Transport Canada, an Agency of the Canadian Federal Government located in Montreal, Quebec, BeauDril Limited of Calgary, Alberta, and the Johnson Rubber Company of Middlefield, Ohio, U.S.A.

Arctec Canada Limited acted as the principal contractor to the project with overall responsibility for the design and installation of the instrumentation, the collection of the data in the field, and the subsequent analysis and reporting of the results.

Arctic Research and Development Ltd. acted as a subcontractor to Arctec Canada Limited, assisting with certain aspects of the experimental design and calibration and with analysis and reporting of certain aspects of the data.

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Mr. Ian Glen	President - Arctec Canada Limited

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17. Abstract

Full scale propulsion tests were conducted on the Class 4 Icebreaker M.V. Kalvik. The program included complete dynamic measurements of the starboard shafting system response, hull bending stresses, and structural accelerations during ice-breaking operations. Unique instrumentation was developed to measure the reactions in each of the two salt-water lubricated rubber stern tube bearings.

The instrumentation was installed in August 1986. Following the drydocking, the M.V. Kalvik proceeded to Resolute Bay, N.W.T., through the Prince of Wales Strait and Viscount Melville Sound. Extensive high speed recordings of the total shafting system response to severe ice milling were made during some eight days of transitting and maneuvering in heavy second-year and multi-year ice.

The program resulted in a detailed description of the response of the shafting and bearings to dynamic ice loads, as well as the determination of the magnitude of forces on propulsion system components. The loads measured on the propulsion system of this vessel are among the highest recorded, and were under some of the most severe ice navigation conditions encountered in the Canadian Arctic.

It is concluded that all of the propulsion train components operated within their design limits, except for the propeller blades and the stern tube seal. An extensive data base suitable to support the development of a modelling methodology for ice class shafting systems was obtained.

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17. Résumé

Ce rapport concerne les essais de propulsion en vraie grandeur effectués à bord du brise-glace de classe 4, N.M. Kalvik, dans le cadre d'une campagne de mesures complètes des contraintes dynamiques sur la ligne d'arbres tribord, des contraintes en flexion de la coque et des accélérations lors des opérations dans la glace. Une chaîne de mesures unique en son genre a été mise au point pour mesurer les contraintes sur chacun des deux paliers d'étambot en caoutchouc, lubrifiés à l'eau de mer.

Après la mise en place de la chaîne de mesures, en août 1986, le brise-glace a quitté Tuktoyaktuk à destination de Resolute, T.-N.-O., via les détroits du Prince-de-Galles et du Vicomte-Melville. Durant les quelque huit jours de marche et de manoeuvre dans des glaces de deux et plusieurs années, des enregistrements à haute vitesse complets des efforts d'ensemble exercés sur la ligne d'arbres ont été effectués.

Cette campagne a débouché sur une description détaillée de la tenue de la ligne d'arbres et des paliers aux charges dynamiques dues à la glace, ainsi que sur la détermination de l'amplitude des forces agissant sur chacun des éléments du système propulsif. Les charges mesurées ont été parmi les plus élevées jamais enregistrées, les conditions de navigation ayant été parmi les plus rigoureuses jamais rencontrées dans l'Arctique.

Il a été déterminé qu'aucun des éléments du système propulsif n'a été sollicité au-delà de sa résistance nominale, à l'exception des pales de l'hélice et de l'étanchéité avant du tube d'étambot.

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Mr. Byron Telle and Mr. Thom Blackie of The Johnson Rubber Company provided valuable expertise and suggestions regarding the instrumentation and installation of the rubber stave stern tube bearings. Their ideas and valuable assistance during the drydocking of the Kalvik are gratefully acknowledged.

The personnel in BeauDril Limited's Arctic operation deserve special acknowledgement. Their highly professional cooperation and help in providing engineering assistance, transportation, accommodation and logistics to the project made a major contribution to its success. Special thanks are extended to Bob Rushton, Dave Lingnau, Steve Schenck, Per Olcen, Jeff Mitchell and Bill Farnworth for their efforts during the docking of the vessel and in the subsequent field program.

The role of Mr. William Forster of BeauDril Limited in facilitating the initial contacts between BeauDril and the other participating organizations is also recognized with thanks.

SUMMARY

Full scale propulsion system tests were conducted on the Class 4 Icebreaker M.V. Kalvik. The program, executed by Arctec Canada Limited on behalf of Transport Canada, BeauDril Limited, and The Johnson Rubber Company, provided for the dynamic measurement of the complete starboard shafting system response to propeller-ice loads, as well as hull bending stresses and structural accelerations during icebreaking operations. Unique instrumentation was developed and installed to measure the dynamic reactions and load distribution in each of the two salt water lubricated rubber stern tube bearings. To the authors' knowledge, such measurements have never before been made at full scale.

The overall objective of the project was to obtain both a quantitative *and* a qualitative understanding of the complete shafting and bearing system response to dynamic ice loads. This understanding, together with the more limited data available from other vessels, is intended to support the development of dynamic modelling techniques for predicting propulsion system component loading in the design of future icebreaking vessels.

This objective was further subdivided into the following goals:

1. To provide full scale engineering data to support improvements to both the design and operating practice for ice-going propellers, shafting and shaft bearings.
2. To extend the base of full scale propulsion system ice load data, begun in 1984 with the M.V. Robert Lemeur, to shafts of higher horsepower and to unducted propellers.
3. To obtain for the first time systematic measurements of the dynamic reactions of propeller shaft bearings to ice impact loads at the propeller.
4. To obtain an accurate qualitative picture of the response of the shafting system to ice loads in order to guide the selection of a suitable idealization for modelling.

The instrumentation was installed when the M.V. Kalvik was drydocked in Arctic Transportation Limited's floating dock, at Tuktoyaktuk, N.W.T., from August 6 - 21, 1986. Following the drydocking, the M.V. Kalvik proceeded to Resolute Bay, N.W.T., through the Prince of Wales Strait. Heavy ice conditions were encountered as the vessel entered Viscount Melville Sound. Repeated ramming through multi-year ice and heavy second year ice was required. Upon arriving in Resolute Bay (August 31, 1986), the M.V. Kalvik joined the CCGS John A. MacDonald. Icebreaking performance tests on the two vessels were conducted from September 2 - 13, 1986, under the terms of a concurrent program conducted for the Canadian Coast Guard. The two vessels operated in second year and multi-year ice floes. Open water trials and ridge ramming trials were conducted from September 12 -13, 1986. The M.V. Kalvik returned to the Beaufort Sea near Tuktoyaktuk, N.W.T. on September 15, 1986.

The instrumentation system functioned as planned and an extensive base of multi-year ice milling data was acquired in an easily accessed format suitable for computer-aided processing and analysis. It is believed that the ice conditions in which this data was obtained are among the most severe in which any icebreaker has been systematically tested, and generally more severe than the conditions in which any existing icebreakers regularly operate.

The successful execution of the project has resulted in a detailed understanding of the response mechanism of the shafting and bearings to dynamic ice loads, as well as the determination of

the magnitude of forces on propulsion system components of the M.V. Kalvik. The following pages present a brief summary of the principal findings of this work.

Findings Regarding the Design of the M.V. Kalvik's Propulsion

1. Measured response to ice loads during these trials did not exceed the design limits of any system components except the propeller blades and the forward stern tube seal.

2. Though there was no evidence of deformation of the propeller blades as a result of this deployment, ice impact loads on the starboard propeller were measured that are in the same range as those required to initiate yielding of the blades. It must be concluded that in extended operations in this type of ice, blade deformation should be expected. This is also consistent with the experience of BeauDril operations personnel who have found all of the blades on both propellers bent slightly forward at previous dockings.

3. The likelihood of blade collapse (i.e., ultimate failure) in this ice condition cannot be assessed based upon the data obtained. The highest loads measured were just sufficient to initiate yielding over a small part of the blade surface and were well below the level needed to break the blade. It is pointed out, however, that the ship was operated very carefully in astern mode to minimize the chance of contact of the propellers and steering gear with massive pieces of multi-year ice.

4. The only one of the shaft bearings forward of the stern tube that experienced significant dynamic loading due to ice-propeller interaction was the aftmost pedestal bearing. The dynamic component of the reaction at this bearing during the most severe ice milling was about 60% of the rated bearing load. It is important that the static load on this bearing be set to a level that will minimize the likelihood of the combined dynamic and static loads exceeding the rating of the bearing. For the present installation on the starboard shaft, the measured static load carried by this bearing is near optimum from this point of view.

5. The maximum measured compression of the rubber stave material near the aft end of the aft stern tube bearing due to ice impact was in the range of 3 to 4 mm, corresponding to a total reaction for this bearing in the range of 150 to 200 tonnes. Regularly occurring ice impact loads of this order do not appear to cause any significant wear or damage to the rubber stave material in periods of one to two years.

   The maximum transient load that can be safely reacted by the rubber stave stern tube bearings is not known explicitly. Based upon the measured data, a load on the order of 600 tonnes would be required to cause the shaft to compress the stave material enough at the aft end of the aft bearing to allow the shaft surface to contact the bearing retaining ring. This is assuming an unworn clearance of 13 mm between the unloaded stave surface and the retaining ring.

   In practice, it is likely that damage to the stern tube seal, the aft pedestal bearing, and possibly the stern frame structure itself, would occur before the shaft would bottom on the retaining ring.

6. In the static condition, the stern tube bearings are both loaded over their full length. The load at the aft end of the aft bearing is about twice as great as at its forward end.

7. In the ice milling condition, both bearings can become unloaded over up to one third of their length, with the peak contact pressure occurring at one end. For the aft bearing, the loading distribution typically alternates between aft end loaded, forward end unloaded and the reverse condition once per blade-ice impact during heavy ice milling. A similar behaviour is seen at the forward bearing. As a result, the aft end of the aft bearing experiences the highest contact pressures, exceeding 7.0 MPa (1000 psi) transiently. Somewhat lower peak loads are seen in the forward end of this same bearing, on the order of 70% of those in the aft end.

   The least loaded part of the aft bearing is a point about 40% of the bearing length aft of the forward end.

8. The most severe ice milling observed in these tests was typically produced by massive ice pieces engaging the bottom of the propeller disk from below.

   The absence of any skeg or structure beneath the propeller boss extending to a depth greater than the bottom of the propeller disk requires large pieces of ice broken at the bow that pass under the bottom of the hull to pass through the lower part of the propeller disk. The buoyancy of the ice helps to maintain its contact with the propeller during its passage of the stern.

   In addition, the fact that the propeller is rotating inboard at the bottom of the disk and the ice is confined on the inboard side by the vertical wall of the centreline skeg further decreases the ice clearing capability of the screw in a severe ice condition and may serve to increase the magnitude of the impact forces experienced by the blades.

   It should be noted that this arrangement of rotation direction would be the preferred one for promoting the escape of smaller pieces of ice from the screw, at least those that are small enough to float up to one side or the other of the boss and thereby encounter the top of the propeller.

Findings Relating to the Operation of the M.V. Kalvik

1. Data obtained in these tests show that extreme axial (i.e., thrust direction) ice induced propeller blade loads can occur with the propeller operating near zero pitch. This has been observed when the ship has some ahead way on and the propeller pitch is reduced to a near zero level while the blades are milling a massive piece of ice that is passing aftward through the bottom of the disk.

2. During heavy ice milling, the transverse movement of the shafting at the location of the stern tube seal routinely exceeds the manufacturer's recommended limits by a factor of up to 2.3. The recommended allowable movement is 1.0 mm. Vertical displacements of up to 2.3 mm and horizontal displacements up to 1.9 mm have been measured.

3. The starboard propeller shaft was automatically declutched in response to ice induced over-torque on five different occasions during these tests. The control system has been set up to declutch the shaft when the torque remains above 1.26 times the MCR torque for more than two seconds.

It is noted that the maximum thrust and bearing reactions recorded during these tests were not measured during any of these declutching events.

The maximum instantaneous starboard shaft torque indicated by the ASEA torque meter during these trials was 1.38 times the MCR torque. The duration of this torque transient above the over-torque limit was less than 0.5 seconds, so that no declutching occurred. As the main reduction gear is supplied to Arctic Class Four requirements which stipulate that the gear be capable of transmitting a shaft torque of 1.6 times the MCR torque it is concluded that the gearbox has operated well within its torsional design limits during these trials.

The combination of great shaft length (i.e., some 30 m from the propeller to the gear box), high rotational inertia aft of the gearbox and the conservative choice of declutch setpoint ensures that the Lohman Box is well protected from ice impact torque transients.

4. There is good evidence in this data of the phenomenon of ice pieces lodging between the propeller disk and the blade of the rudder during ahead operation with the rudder hard over. The result is to cause a transfer of mechanical impact from the blades through the ice to the rudder and then to the steering gear. The resulting impacts recur once per blade until the ice is dislodged or the pitch or rudder angle is changed.

   The amplitude of the rudder stock torque response can be of the same order as torques caused by moderate sized ice blocks hitting the rudder blade in backing operations. The recorded loads due to this effect were not sufficient to cause the rudder hydraulic relief valves to act, but could be significant in causing progressive fatigue damage to the linkages at the steering yoke.

5. Although the total reactions measured in the aftmost pedestal bearing were within the load rating for this bearing, it is clear that the loads at this point are governed by the amplitude of a long dynamic bending wave excited on the aftmost 12 m or so of the shaft line when ice impacts occur at the propeller. The amplitude of this bending wave in turn is influenced by the available clearance in the two rubber stave bearings.

   This implies that there may be a need to limit the allowable wear down of these bearings for use in ice operations differently than would be the case for open water operations. This does not appear to be a significant consideration for this vessel in its present operating environment as negligible wear down of the bearings has been observed to date. If, however, the vessel was to perform ice breaking duties in heavily silted water where accelerated bearing wear was a problem, this would be an important factor to monitor.

6. The bending of the hull girder of the M.V. Kalvik, during the ramming of heavy ice ridges, does not induce significant loading on the shafting and bearings.

7. The gyroscopic reactions at the flywheel bearings to yawing or pitching accelerations of the hull caused by ramming heavy ice features are entirely negligible for this installation.

Findings of Importance to the Modelling of Propulsion Ice Loading

1. The dynamic loading of the shaft bearings due to ice propeller interaction can be modelled by the propagation of a transverse bending wave along the shafting.

2. The longitudinal distribution of load within long stern tube bearings can also be accounted for in terms of the shaft bending model.

3. The measured axial and in-plane components of the ice impact loads on the propeller disk are consistent with order-of-magnitude calculations of such forces based upon the geometry of the loading indicated by milled ice block observations and ice mechanics considerations.

4. Both the axial (thrust) and in-plane (torque related) components of the propeller-ice impact force can contribute to the excitation of shaft bending that transfers dynamic reactions to line bearings inboard. The resulting shaft deformation is in fact a compound bending in two planes.

5. The presence of geometrical constraints preventing ice pieces from escaping from the propeller disk such as nearby skegs or rudders must be considered when modelling the duration and amplitude of ice milling forces acting on the propeller.

6. The transverse bending model of the shaft, together with a knowledge of ice induced exciting forces, should be useful in locating bearing support points and seals to minimize displacements and reactions at these components.

7. For relatively short, deep icebreaking hulls such as the Kalvik's, the stiffness of the aft hull girder in bending is such that ramming operations do not produce foundation displacements sufficient to generate significant reactions at the shaft bearings.

In addition to the foregoing general findings, the data obtained in the course of this work contains many sets of quantitative results relating shaft torque and thrust response to shaft movements and bearing reactions. These data are obtained for numerous events spanning the full range of pitch and rudder angle settings and for both ahead and astern operating conditions. These data sets would provide an extensive set of test cases to help validate the predictive power of a generalized ice class shafting design model.

SOMMAIRE

Des essais de propulsion en vraie grandeur ont été effectués à bord du brise-glace de classe arctique 4 N.M. Kalvik, dans le cadre d'une recherche conduite par Arctec Canada Limited pour le compte de Transports Canada, BeauDril Limited et The Johnson Rubber Company. Il s'agissait de mesurer les contraintes dynamiques sur la ligne d'arbres tribord dues à la charge des glaces sur l'hélice, les contraintes en flexion de la coque et les accélérations lors des opérations de déglaçage. Une chaîne de mesure unique en son genre a été étudiée et installée pour mesurer la distribution de la charge et les contraintes dynamiques exercées sur chacun des deux paliers en caoutchouc du tube d'étambot, lubrifiés à l'eau de mer. De l'avis des auteurs, jamais auparavant ces mesures n'avaient été faites en grandeur réelle.

L'objectif global de la recherche était l'obtention de données quantitatives en vue de mieux appréhender la réponse de la ligne d'arbre et des paliers aux charges exercées. Ces données, ajoutées à celles moins abondantes fournies par des essais antérieurs faits sur d'autres navires, doivent servir à la mise au point de techniques de modélisation dynamique permettant de calculer les charges sur chacun des organes du système propulsif qui équipera les brise-glace à l'étude.

Cet objectif global comportait à son tour les sous-objectifs suivants:

1) Recueillir des données en vraie grandeur utilisables par les ingénieurs pour la conception d'hélices, de lignes d'arbres et de paliers résistant à la charge des glaces et aussi de techniques d'exploitation améliorées.

2) Étendre la base des données sur la charge des glaces commencée en 1984 à bord du N.M. Robert-Lemeur et l'élargir aux navires de plus forte puissance sur l'arbre ou équipés d'hélices non carénées.

3) Procéder pour la première fois à la mesure systématique de la réponse dynamique des paliers aux charges exercées par les glaces sur les hélices.

4) Schématiser avec précision cette réponse de manière à faciliter le choix de paramètres idéalisés pour la modélisation ultérieure.

Après la mise en place de la chaîne de mesure entre le 6 et le 21 août 1986, le N.M. Kalvik a quitté le bassin de radoub flottant d'Arctic Transportation Limited à Tuktoyaktuk (Territoires du Nord-Ouest) pour entreprendre un périple à destination de Resolute Bay, via le détroit du Prince-de-Galles. Dans le détroit Vicomte-Melville, il a rencontré des champs de glace de plusieurs années et de deuxième année de forte épaisseur qu'il a dû négocier à maintes reprises. Arrivé à destination, le 31 août 1986, il s'est joint au brise-glace John A. MacDonald et ensemble, du 2 au 13 septembre, ils ont effectué des essais de performance pour le compte de la Garde côtière canadienne, dans le cadre d'un programme de déglaçage qui les a menés à opérer des floes de deuxième année et de plusieurs années. Puis, les 12 et 13 septembre, ils ont procédé à des essais en eau libre et contre des crêtes de glace; enfin, le 15 septembre, le N.M. Kalvik était de retour dans la mer de Beaufort au large de Tuktoyaktuk.

La chaîne de mesure a bien fonctionné, fournissant des données abondantes sur le broyage des glaces de plusieurs années, dans un format facilement exploitable par les dispositifs de traitement et d'analyse assistés par ordinateur. Les conditions de glace correspondantes ont sûrement été parmi les plus rigoureuses qu'un brise-glace ait jamais eu à affronter lors d'essais systématiques; elles sont en tout cas plus rigoureuses que celles normalement rencontrées par un brise-glace.

La recherche a débouché sur une compréhension approfondie de la réponse des paliers et lignes d'arbre aux charges dynamiques des glaces et de l'amplitude des efforts s'exerçant sur les organes du système propulsif. Voici un bref aperçu des principales conclusions auxquelles les chercheurs sont arrivés.

Conclusions concernant la tenue du système propulsif du N.M. Kalvik

1. Il a été déterminé qu'aucun des organes du système propulsif n'a été sollicité au-delà de sa résistance nominale, à l'exception des pales d'hélice et de l'étanchéité avant du tube d'étambot.

2. Bien qu'aucune des pales des hélices n'ait montré des signes de déformations, les charges d'impact subies par l'hélice tribord ont été du même ordre que la limite élastique des pales. D'où la conclusion qu'il faut s'attendre à une déformation des pales lorsque les opérations de déglaçage dans des glaces de ce type se prolongent. Cette conclusion va dans le sens des constatations faites par BeauDril à l'occasion de radoubs antérieurs du navire, soit que les pales des deux hélices avaient été légèrement tordues vers l'avant.

3. A partir des données recueillies, il n'est pas possible d'estimer les probabilités d'une rupture de pale dans les conditions de glace décrites. Toutefois, on sait que les charges maximums mesurées avaient une amplitude telle que la limite élastique d'une petite surface de l'hélice a pu être dépassée, mais qu'elle a été bien au-dessous de celle nécessaire pour entraîner la rupture. Il faut cependant faire observer que, en marche arrière, toutes les précautions avaient été prises pour réduire au minimum les risques de contact des hélices et de l'appareil à gouverner avec de gros fragments de glaces de plusieurs années.

4. Le palier sur appui le plus rapproché du tube d'étambot a été le seul parmi les paliers à l'amont du tube d'étambot à subir une charge dynamique importante due à l'interaction glace-hélice. La composante dynamique des sollicitations les plus fortes exercées sur ce palier s'est élevée à quelque 60 p. 100 de sa résistance nominale. Il y a lieu de préciser que la charge statique sur ce palier doit être telle que la somme de celle-ci et de la charge dynamique ne risque pas de dépasser la résistance nominale du palier. De ce point de vue, on peut dire que la charge statique mesurée au droit de ce palier est optimale pour ce qui concerne l'arbre tribord dans sa configuration actuelle.

5. La compression maximum mesurée sur l'extrémité arrière du palier arrière en caoutchouc du tube d'étambot, et attribuable à la charge des glaces, a été de l'ordre de 3 à 4 mm, ce qui correspond à une réaction totale de ce palier de 150 à 200 tonnes. Or, il est peu probable qu'avec des charges périodiques de cet ordre, l'usure ou l'endommagement du palier puisse être visible de manière durable avant un ou deux ans d'opérations.

La charge transitoire maximale que les paliers en caoutchouc du tube d'étambot peuvent absorber n'est pas connue. Mais, se fondant sur les données recueillies, une charge de l'ordre de 600 tonnes serait nécessaire pour que l'arbre exerce sur la partie arrière du palier arrière du tube d'étambot une force telle qu'il entre en contact avec la bague de retenue. Ceci, en supposant qu'il y ait un jeu net de 13 mm entre le palier non chargé et la bague.

Dans la réalité, il est probable que l'étanchéité du tube d'étambot, le palier sur appui arrière et peut-être aussi la membrure arrière du navire soient endommagés avant même l'éventualité d'un tel contact.

6. En régime statique, les deux paliers du tube d'étambot sont chargés sur toute leur longueur. La charge s'exerçant sur la partie arrière du palier arrière est à peu près le double de celle s'exerçant sur la partie avant.

7. En situation de broyage des glaces, les deux paliers d'étambot peuvent connaître un allègement sur près d'un tiers de leur longueur, la pression de contact maximale se produisant à l'une des deux extrémités. Concernant le palier arrière, la charge se déplace alternativement entre la partie avant et la partie arrière, l'une ou l'autre se trouvant momentanément allégée chaque fois qu'il y a impact d'une pale contre des glaces très dures. Le même phénomène touche le palier avant. La pression de contact la plus élevée s'exerce donc sur la partie arrière du palier arrière; elle peut momentanément dépasser les 7 MPa (1000 lb/po2). La pression maximum sur la partie avant de ce même palier est quelque peu moins forte, de l'ordre de 70 p. 100.

   La partie du palier arrière la moins chargée se situe en un point à quelque 40 p. 100 de sa longueur par rapport à son extrémité avant.

8. L'effort de broyage le plus intense mis en évidence se produit lorsqu'un gros fragment de glace frappe la partie inférieure de l'hélice dans une direction ascendante. L'absence d'un talon ou d'un dispositif quelconque placé sous la coque et se projetant plus bas que le cercle de rotation de l'hélice, fait que les gros fragments de glaces brisés par l'étrave et repoussés sous la coque touchent l'hélice lorsqu'ils remontent vers la surface à la partie arrière du navire.

   De plus, étant donné que dans la moitié inférieure du cercle de rotation les pales de l'hélice tournent vers l'intérieur, l'aptitude de l'hélice à dégager un fragment de glace coincé s'en trouve encore plus affaiblie, ce qui amplifie la force de l'impact sur les pales.

   Ce sens donné à la rotation de l'hélice reste cependant préférable car il permet aux fragments de glace plus petits de s'échapper sans heurter l'hélice, du moins ceux assez petits pour que, remontés à la surface de part ou d'autre du moyeu, ils puissent être chassés par la rotation de l'hélice en sa partie supérieure.

Conclusions concernant l'exploitation du N.M. Kalvik

1. Les résultats des essais ont montré que les charges axiales les plus fortes exercées sur les pales se font sentir lorsque le pas de l'hélice approche le zéro. Ce phénomène se produit quand le navire marche sur son erre, que le pas de l'hélice est ramené près de zéro et qu'un gros fragment de glace se déplaçant vers l'arrière franchit le cercle de rotation de l'hélice.

2. Sous un effort de broyage intense, les déplacements transversaux de l'arbre à l'intérieur de l'étanchéité du tube d'étambot sont généralement tels qu'ils dépassent les limites prescrites par un facteur pouvant aller jusqu'à 2,3 (le déplacement admissible étant de 1 mm). Les résultats font état de déplacements verticaux et horizontaux maximums de 2,3 et 1,9 mm, respectivement.

3. En cinq cas distincts de couple excessif attribuable à la charge des glaces, le débrayage automatique de l'arbre porte-hélice tribord s'est produit. Un tel débrayage est prévu lorsque le couple atteint 1,26 fois celui correspondant à la puissance maximale continue pendant plus de deux secondes.

   A noter que la poussée maximale et la réaction maximale dans les paliers enregistrées lors des essais n'ont pas eu lieu au moment où se produisait le couple excessif entraînant le débrayage automatique.

   Le couple instantané maximal sur l'arbre tribord indiqué par le torsiomètre ASEA a été de 1,38 fois le couple à la puissance maximale continue, mais comme il a duré moins d'une demi-seconde, aucun débrayage ne s'en est suivi. Étant donné que le réducteur principal équipant les navires de classe arctique 4 doit, selon le règlement, pouvoir transmettre un couple égal à 1,6 fois le couple à la puissance maximale continue, on en déduit que ce réducteur n'a pas été sollicité au-delà de sa résistance en torsion durant les essais.

   Le réducteur Lohman est protégé contre les couples momentanés dus à la charge des glaces par un ensemble de trois facteurs: grande longueur d'arbre (près de 30 m entre la boîte et l'hélice), inertie de rotation élevée à la sortie du réducteur et points de débrayage situés bien au-dessous des seuils limites.

4. Les résultats obtenus rendent bien compte du phénomène résultant du coincement de fragments de glace entre l'hélice et le safran du gouvernail, lorsque le navire avance et que la barre est braquée toute. L'effort de broyage est reporté sur l'appareil à gouverner via le fragment et le gouvernail, les chocs se succédant à mesure que les pales frappent le fragment jusqu'à ce que celui-ci s'échappe ou que l'angle de barre change.

   La réponse torsionnelle de la mèche du gouvernail est à peu près du même ordre que celle résultant du choc de fragments de glace de dimensions moyennes contre le safran quand le navire fait marche arrière. Même si les charges correspondantes n'ont pas réussi à actionner les clapets de décharge automatique, elles sont néanmoins suffisantes pour provoquer l'usure progressive par fatigue des tringles commandant le palonnier du gouvernail.

5. Bien que la charge totale encaissée par le palier sur appui arrière n'ait pas dépassé la résistance nominale de ce dernier, cette charge est de toute évidence régie par l'amplitude d'une onde de flexion longue située à peu près dans les derniers douze mètres de l'arbre, elle-même excitée par l'impact des glaces sur l'hélice. Quant à l'amplitude de cette onde, elle est à son tour régie par le jeu net à l'intérieur des deux paliers en caoutchouc.

   Ce phénomène aurait pour conséquence que le calcul du taux d'usure admissible à l'égard de ces paliers serait différent selon qu'il s'agisse d'une exploitation en eau libre ou bien d'une exploitation dans les glaces. Dans les conditions d'exploitation actuelles, cette considération ne semblerait pas avoir, pour le navire considéré, une importance capitale, le taux d'usure constaté jusqu'ici restant négligeable. Mais les choses pourraient devenir tout autres si, par exemple, les opérations de déglaçage devaient se faire dans des eaux lourdement saturées de vase, ce qui provoquerait dans les paliers une usure très rapide.

6. La flexion de la poutre-navire due à la charge des crêtes épaisses n'a chargé ni l'arbre ni les paliers outre mesure.

7. Les effets gyroscopiques au niveau des paliers du volant, induits par les mouvements de tangage et de lacet résultant de la charge des glaces, n'ont aucune influence sur cette installation.

Conclusions importantes concernant la modélisation de la charge des glaces

1. Il est possible de modéliser la charge dynamique qui s'exerce sur les paliers en faisant se propager l'onde de flexion transversale le long de la ligne d'arbre.

2. À l'intérieur des paliers de tube d'étambot de grande longueur, la distribution axiale de la charge peut être prise en compte par le modèle représentant la flexion de l'arbre.

3. Les composantes axiale et radiale des forces d'impact des glaces sur l'hélice tournante sont du même ordre que les valeurs calculées à partir des caractéristiques géométriques de la charge déterminées tant par des observations du phénomène de broyage que par la connaissance des propriétés mécaniques des glaces.

4. Les composantes axiale (poussée) et radiale (couple) des forces d'impact contribuent, elles aussi, à provoquer la flexion de l'arbre qui a pour effet de susciter des réactions dynamiques dans les paliers. La déformation qui en résulte n'est autre qu'une flexion double agissant dans deux plans.

5. L'influence de barrières (semelle d'étambot, gouvernail), empêchant les fragments de glace d'être chassés par l'hélice, doit être prise en compte dans la modélisation, en durée et en amplitude, des efforts de broyage.

6. La modélisation de l'onde de flexion transversale et la détermination des forces d'excitation de l'arbre pourraient servir à l'implantation plus précise des supports de paliers et des étanchéités, débouchant ainsi sur une minimisation des déplacements et des réactions de l'arbre à l'intérieur de ces organes.

7. Dans le cas du Kalvik, caractérisé par une coque profonde, relativement courte et apte au déglaçage, la raideur en flexion de la poutre-navire à l'extrémité arrière est telle que les marches alternées ne provoquent pas, dans les supports de paliers, des déplacements susceptibles de produire à leur tour de fortes réactions.

En plus de ces résultats, la recherche a permis de recueillir une documentation riche permettant de mettre en rapport le couple à l'arbre et la poussée correspondante avec les mouvements de l'arbre et les réactions à l'intérieur des paliers. Les événements ayant donné lieu à cette documentation sont nombreux, couvrant toute la gamme des réglages du pas de l'hélice et de l'angle de braquage, tant en marche normale qu'en marches alternées. Cette documentation permettra en outre d'illustrer un certain nombre de cas d'espèce susceptibles d'aider à valider le modèle généralisé de conception de la ligne d'arbre devant équiper un navire de classe arctique.

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NOMENCLATURE

A	Cross Sectional Area
C	Damping
d	Diameter
E	Elastic Modulus
F	Thrust and Force
G	Modulus of Rigidity
I_p	Polar Moment of Inertia
k	Stiffness
L	Length
Q	Torque
SM	Sectional Modulus
T	Time
V_s	Velocity of Vessel
Φ	Angular Twist
ρ	Density of Steel
σ	Stress
σ_y	Yield Stress
μ	10^{-6}

1. INTRODUCTION

During the past ten years major advances have been made in improving the understanding of underlying phenomena important in the design of ice-going shipping. In Canada, much of this work has been motivated by the recognition of a growing need for much larger and more ice-capable ships than have ever before been constructed, if the goal of year-round navigation in the Canadian Arctic is to be achieved. It is understood that it will be difficult to extrapolate the design criteria for such vessels from the experience of existing, much smaller and less powerful shipping, without a sound appreciation of the basic physical processes involved.

One of the least well understood aspects of the design of ice-going shipping is the problem of dynamic loading of propellers, shafting and shaft bearings due to ice blocks passing through the propellers. Current design practice has been largely heuristic: propellers, shafting and bearings have been progressively strengthened in response to the occurrence of damages encountered in operational icebreakers and ice-going merchant ships. Nonetheless, damage to propellers, shaft seals and shaft bearings continues to be a major problem, even in the newest and most powerful ice-going ships.

Propulsion System Damage in Ice-Going Ships

Within the past ten years, major damage has been sustained to controllable pitch propeller mechanisms in ice (on the USCG Polar class icebreakers and on the Soviet SA-15 Arctic Merchant ships), as well as to the blades of fixed pitch propellers (propeller blades have been broken on Canadian Coast Guard and Finnish Board of Navigation ships, as well as Soviet icebreakers and ice-going merchant ships operating in heavy ice). Lesser catastrophic failures have included bending of propeller blades in ice, frequent damage to shaft seals and a number of instances of delamination and excessive wear of shaft stern tube bearings composed of man-made synthetics. These problems appear to be all but universal in the ice-going fleets of many nations and are responsible for a significant part of the downtime and total cost of maintenance of ice-going shipping.

Pyramidal Strength Design Approach

To some extent the continuing failure of propeller blades and pitch setting mechanisms in ice represents the success of current design philosophy in preventing more catastrophic forms of failure. Propeller blades and controllable pitch mechanisms must be designed so that they will be assured of failing under extreme loads before the tailshaft itself, thereby protecting that most critical part of the ship. The philosophy of designing various propulsion system elements according to a strength heirarchy that ensures that non-catastrophic failures occur at lower loads than catastrophic failures, thereby reducing the likelihood of the more serious failures, is often referred to as the pyramidal strength design approach.

Nonetheless, the continued frequency of main propulsion system damage in icebreakers indicates that the overall strength requirements of such systems are still not predictable in terms of a sound design methodology well supported with engineering data.

Types of Loading Considered in Current Design Practice

Most of the loading conditions considered in developing propulsion system design solutions in the present state of the art consider only static loads or periodic loads analogous to water borne propeller loads augmented by a "factor of safety" to account for ice loading. Such factors of safety for example, are applied to increase the hub/diameter ratio, the thickness of propeller blades and the thrust and torque handling capacity of the shafting system for use in ice.

Experimental observations of ice impact loading using high speed measurements has revealed, however, that the complex transient nature of such loads may produce new and unexpected modes of loading not anticipated by existing design practice. In addition, load amplitudes can be significantly affected by the dynamic characteristics of the system and the manner in which it is operated.

The M.V. Robert Lemeur Propeller Blade Load Tests

In 1984, a joint industry project conducted by the Transportation Development Centre (TDC) of Transport Canada and CANMAR successfully measured at full scale, the dynamic loading of a propeller blade of a 4500 HP ducted controllable pitch propeller on CANMAR's Arctic Class Three Icebreaking supply vessel, the M.V. Robert Lemeur. This provided the first reliable qualitative picture of the ice loading phenomenon for this type of propulsor as well as quantitative blade load data. Some limited data relating to shaft movements in response to propeller ice induced loads were also obtained.

One of the important observations of this work was that the actual modes of loading of various system components, including both blades and pitch setting mechanism, was very different from that assumed by the methodology used to design the propeller.

Behaviour of Shafting in Unducted Ice-Going Propellers

The unexpected findings of the M.V. Robert Lemeur program suggested a related problem: How might the shafting and bearing system response to ice loads differ from that assumed in the design process? A number of important questions lacked any answer grounded in observation:

What are the transverse loads that must be reacted by the stern tube shaft bearings due to ice ingestion at the propellers, particularly in unducted systems where very massive pieces of ice can engage the propeller? Can such loads be predicted from the characteristics of the ice and the propulsor? What effect does the geometry of the surrounding hull have on the amplitude of such loads? What kinds of ice operations cause the highest loading of the the shafting and its bearings? Is there coupling between the torsional, axial and transverse responses of the shafting system to ice loads? How do transverse loads on the shafting propagate into the ship affecting the reactions at other bearings? Can hull bending deflections caused by ramming operations in ice cause transient misalignment conditions contributing to bearing damage?

M.V. Kalvik Propulsion System Tests

The program of full scale measurement which is the subject of this report was defined by TDC to provide a base of engineering data that could be used to address the problems of shafting design for dynamic response to ice impact loads at the propellers. The project resulted from discussions held between BeauDril Limited, TDC and Arctec Canada Limited in April and May of 1986. BeauDril Limited had expressed interest in instrumenting one propulsion train of their twin screw Arctic Class Four Icebreaker, the M.V. Kalvik, at a drydocking planned for August 1986. This was with a view to measuring the ice loads acting on the propeller blades, as some slight but consistent deformation of all of the blades had been noted at previous dockings.

It was recognized by all parties that, as both shafts had to be drawn from the ship for routine maintenance work, an excellent opportunity was at hand to carry out a thorough instrumentation of the propulsion train of one of Canada's most powerful ice-going vessels, and to obtain unique information of benefit to operators and designers of ice class shipping.

After considering the information requirements of both Transport Canada and BeauDril Limited, a plan was prepared for a program of full scale measurements onboard the M.V. Kalvik having the following objectives:

1. To provide full scale engineering data to support improvements to both the design and operating practice for ice-going propellers, shafting and shaft bearings.

2. To extend the base of full scale propulsion system ice load data, begun with the M.V. Robert Lemeur, to shafts of higher horsepower and to unducted propellers.

3. To obtain systematic measurements of the dynamic reactions of propeller shaft bearings to ice impact loads at the propeller.

4. To obtain an accurate qualitative picture of the response of the shafting system to ice loads in order to guide the selection of a suitable idealization for modelling.

The project plan called for the detailed instrumentation of one of the M.V. Kalvik's two shaft lines, including the measurement of dynamic reactions in each of the two rubber stave stern tube bearings.

The Johnson Rubber Company, the manufacturer of the rubber stave stern tube bearings used in the M.V. Kalvik, was contacted regarding the feasibility of providing a replacement shaft set of bearings that could be instrumented for local bearing contact pressure in time to meet the ship's docking schedule. The Johnson Rubber Company provided assurance that such a set of bearings could be provided in time and agreed to become a participant in the project contributing the new shaft set of bearings and engineering assistance in modifying them for instrumentation and in installing them in the ship.

The BeauDril Arctic Class Four Icebreaker M.V. Kalvik

Figure 1.1 presents the general arrangement of the M.V. Kalvik. Table 1.1 presents the principal particulars of this vessel. The M.V. Kalvik is an icebreaking, anchor handling tug and supply vessel designed and built specifically to support BeauDril's Arctic Oil exploration program in the Beaufort Sea. It was delivered from its builder, Burrard Yarrows Corporation of Vancouver, B.C. in July of 1983. At 6820 tons displacement and 23,200 BHP, the M.V. Kalvik is one of the largest and most powerful privately owned icebreakers in the world. The M.V. Kalvik incorporates a number of design features that have been pioneered by Oil Exploration companies in the Canadian Beaufort for their support fleet icebreakers.

The hull is largely constructed of flat or single curvature plate to reduce the time and cost of construction. The propulsion system consists of two LIPS ice strengthened controllable pitch propellers each capable of absorbing 11,000 HP. Each propeller is directly driven by a pair of Stork Werkspoor Medium Speed Diesel engines through a Lohman & Stohlterfoht 600:130 main reduction gear. The shaft torque is continuously monitored on each shaft by a torductor electromagnetic torsion metering system provided by ASEA, who also provide the propulsion system digital controls. Each engine engages its gear pinion through an air clutch that can be programmed to automatically open if a preset torque level sensed by the torductor is exceeded for a preset time interval (1, 2 or 3 seconds typically).

Of importance to this project was the fact that the M.V. Kalvik's propellers are unducted. As data had previously been obtained in the M.V. Robert Lemeur for a ducted propeller, the opportunity to observe the differences in ice loading occurring in an unducted installation was considered to be important. The propellers are also set well out from the hull on long projecting bosses stiffened to the hull by a vertical skeg. The ship has a single rudder at the aft end of a deep centerline skeg which extends from the ship's keel line up to the underside of the stern between the two propellers.

Finally, the M.V. Kalvik's history of successful operation for three years in the Beaufort Sea provided the assurance that she could be safely operated in the severe multi-year ice conditions which would yield the most important data from the point of view of ongoing development of propulsion design criteria.

Project Chronology

Negotiation of a project agreement between TDC, BeauDril Limited and The Johnson Rubber Company as contributory participants in the project and Arctec Canada Limited as principal contractor took place during the period April to July of 1986. During this time, a work statement was prepared and agreed upon which specified the objectives of the work, the scope of the instrumentation to be provided and the program of data collection that was to be carried out with the instrumented vessel.

The instrumentation system was designed to measure, on a common time base, enough parameters to fix the instantaneous state of loading of the starboard shaft line as well as the response of its foundation. High speed time series data for all of these parameters would be stored automatically whenever ice impact loads were experienced by this shaft that exceeded operator selected setpoints. In this way, the data collection could be carried out with relatively few personnel onboard to operate the instrumentation and with minimum impact upon the vessel's ongoing operations.

Contractual and Confidentiality Agreements

Two agreements were concluded between the three contributory participants and Arctec Canada Limited, one of which provided for the scope and definition of the work, and a second in which all parties privy to the project and its results undertook to hold such information in confidence for a period of two years excepting such disclosures as were consented to by all three contributory participants.

Preparatory Investigations and Instrumentation Work

In June, Arctec Canada Limited personnel received drawings and technical information regarding the M.V. Kalvik and its outfit from BeauDril Limited to begin the detailed design of instrumentation needed for the project. Arctec Canada Limited engineering staff also visited the M.V. Kalvik in the Beaufort Sea to conduct an onsite inspection of the vessel with a view to assessing potential problems and possible solutions for instrument installations.

During July, sections of the rubber stave material used in the M.V. Kalvik's bearings were obtained from The Johnson Rubber Company and submitted to mechanical investigation by Arctec Canada Limited's Calgary staff to determine their properties for load measurement by experimental stress analysis techniques. The design of the instrumentation system was then finalized, and materials and equipment were assembled in Calgary preparatory to the field instrumentation work to be carried out during the drydocking of the vessel.

During July, Arctec Canada Limited personnel also travelled to The Johnson Rubber Company plant in Middlefield, Ohio to finalize, with Johnson staff, the design of the machining to be done to the rubber staves to accommodate the installation of sensors and cabling. The machining was carried out by The Johnson Rubber Company and concurrently, the installation of sensors, cabling and sealing was done by Arctec Canada Limited personnel at Johnson's Middlefield facility. This work was completed by the end of July.

The instrumented shaft set of bearings and all of the tools and equipment needed to perform the instrumentation work during the docking of the vessel were flown to Tuktoyaktuk, N.W.T., in early August. Prior to the docking of the vessel, Arctec Canada Limited personnel, together with the TDC project officer, boarded the M.V. Kalvik and carried out a survey of the static alignment condition of the starboard shaft using strain gauge techniques to establish the baseline condition of this shaft line prior to docking.

Drydocking and Installation of Instrumentation

The vessel was lifted on a floating drydock in deep water and brought into Tuktoyaktuk for the second and third weeks of August. During this time, all of the stern tube instrumentation was fitted and the associated cabling installed. In addition, much of the fitting of instrumentation in the internal machinery spaces was carried out while the vessel was on the dock. After the undocking, a second survey of the static alignment condition of the starboard shaft was performed.

The fitting and connection of the remainder of the instrumentation in the machinery spaces was completed during the last few days of August while the ship was proceeding through Amundsen Gulf and the Prince of Wales Strait enroute to Resolute Bay. The data collection system was placed in operation just as the ship entered ice at the north eastern end of Prince of Wales Strait.

Data Collection: The Voyage From Tuktoyaktuk to Resolute and Return

During the period immediately preceding the M.V. Kalvik's docking, BeauDril Limited negotiated a separate contract with the Canadian Coast Guard for the charter of this vessel to undertake a return voyage from Tuktoyaktuk to Resolute Bay following its drydocking. The purpose of this voyage was to enable the Canadian Coast Guard to evaluate the various design features of the M.V. Kalvik for suitability in the range of operations required of Coast Guard icebreakers, and in the severe ice conditions typical of a key portion of the North West Passage (i.e., western Viscount Melville Sound). This voyage proved to be an extremely valuable opportunity for the collection of propulsion system ice loading data.

The Tuktoyaktuk to Resolute return voyage was carried out between August 26 and September 15, 1986. The ship encountered three days of extremely heavy icebreaking operations in the multi-year floes characteristic of western Viscount Melville Sound during the outbound leg of the voyage. During the return portion extensive maneuvering, both in heavy ice and in open water, was carried out as part of the vessel's performance evaluation, providing the opportunity to observe and measure the response of the propulsion system and shafting under a wide range of conditions up to the limiting ice regime for effective operation of a vessel of this size.

During this time, some ninety-two high speed digital recordings were made of the shafting response to ice and water loads, each of which contains up to forty individual propeller blade-ice impacts. Individual blade forces in excess of 200 tonnes were measured. Extensive documentation and characterization of the ice environment was obtained in concert with the work carried out for Coast Guard to measure the vessel's performance. The vessel routinely operated in second year and older floes having a typical thickness of one and half to two meters, and performed ramming operations in multi-year ridges up to nine meters in thickness. Individual multi-year ice blocks having a mass of more than 100 tonnes were observed to emerge from beneath the stern of the vessel heavily scored and milled across their entire length by the propeller blades. In the opinion of the authors, who have collectively been involved in most of the full scale icebreaker trials work conducted in North America during the past ten years, the ice regime encountered on this voyage was one of the most severe in which systematic measurements have yet been conducted on ship and machinery performance.

Analysis and Reporting

Subsequent to this voyage, the instrumentation onboard the vessel was de-commissioned as the operational plan for the vessel for the balance of the season did not envision any further ice operations that would be expected to yield information not already obtained in the course of this voyage. Processing and analysis of the data progressed from October, 1986 to February, 1987 at Arctec Canada Limited's Calgary facility with preliminary presentations of some of the early findings being made to BeauDril Limited and to TDC in December of 1986. The preparation of this report, documenting the findings of the project, was carried out during February and March 1987.

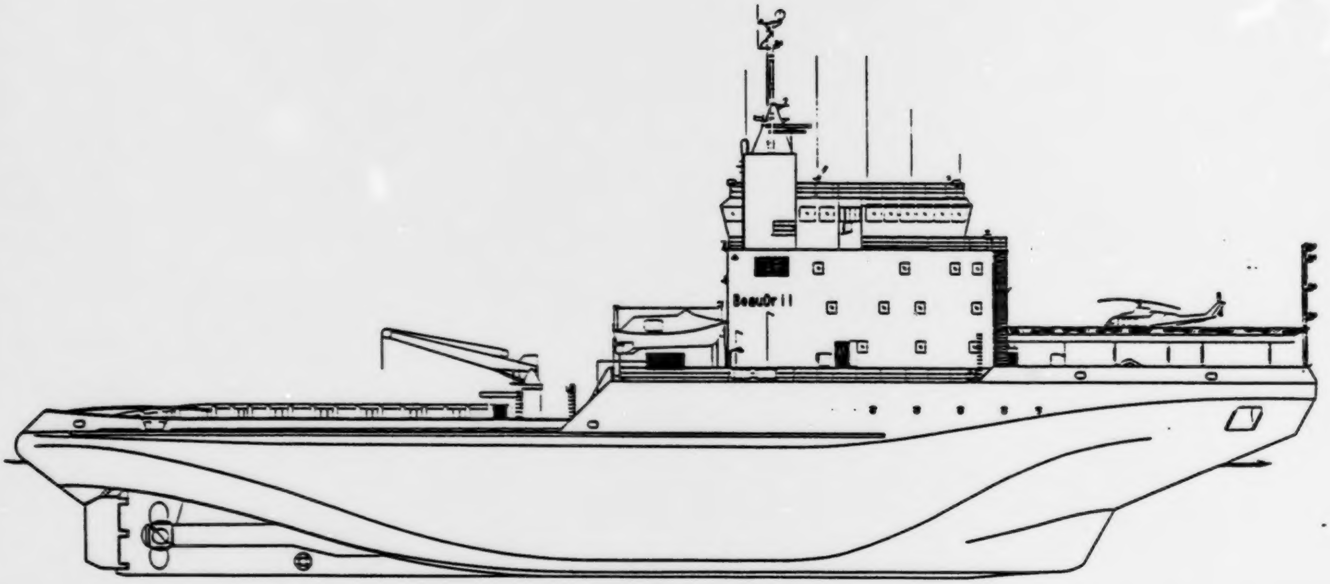
Organization of This Report

This report is organized under two covers as follows:

1. The main body of the report, divided into ten (10) sections.
2. The appendices to the report, organized as seven (7) appendices.

This introduction constitutes the first section of the main report. The five following sections present and describe the work done within the scope of each of the first five of the six tasks identified in the work statement which forms the basis of the agreement between the parties involved in this project. The sixth task in the work statement is the reporting itself.

The contractual and confidentiality agreements among the participants, including the statement of work, are presented in Appendix A. A listing and description of the data products resulting from this work is presented in Appendix G.



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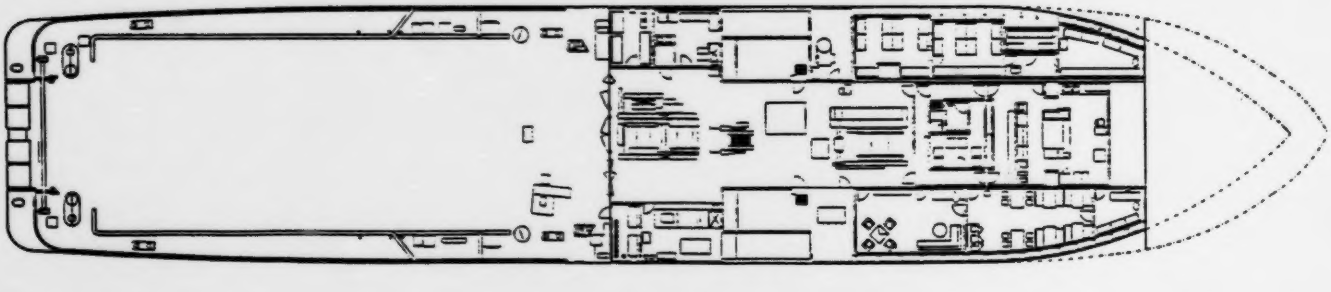


MAIN DECK

Figure 1.1. General Arrangement

Table 1.1 Ship's Particulars

Ship's Particulars

General Information

Designed By:	German and Milne Inc.
Built By:	Burrard Yarrows Corporation (Victoria) Division
Keel Laid:	June 21, 1982 (Esquimalt, B.C.)
Hull Number:	5-54
Launched:	April 2, 1983
Delivered:	July 22, 1983
Owners:	BeauDril Limited
Official Number:	803564
Call Sign:	VY 9403
Flag:	Canadian
Port of Registry:	Vancouver, B.C.
Type:	Ice-breaker, Anchor-handling, Supply, Tug
Class:	ASPPR Ice Class 4
Lloyds Class:	100A1 Ice-Breaker, Tug
Voyage Class:	Home Trade 1
Berths Total:	34
Crew:	19
Helideck:	Can handle up to Bell 214 ST (with skids)

Dimensions

Length O.A.:	88m
Length B.P.:	75m
Breadth Extreme:	17.82m
Depth Moulded:	To Main Deck—10m
Draft Extreme:	8.3m

Tonnage

Gross Tonnage:	4219.39
Net Tonnage:	1970
Deadweight Winter Draft:	1866.95
Displacement Winter Draft:	6820.95

Deck (Loading Capacities)

Deck Measurements:	34m x 13m
Deck Cargo Capacity:	800 tonnes
Bulk Barite/Cement Capacity:	34m^3 x 3 = 102m^3
Fuel Oil:	1 918.56m^3
Drill Water:	1 432.38m^3
Fresh Water:	40

Engine

Main Engine:	(4) Stork Werkspoor Diesel
RPM:	600
BHP:	23,200
Thrusters FWD:	Wartsila Air Bubbler System
Thrusters AFT:	Kamewa CPP
Fresh Water Maker Capacity:	10 tonnes/day
Propellers:	2 LIPS, N.V. C.P. 4 blades
Bollard Pull:	Over 220 tonnes
Service Speed (two engines):	13.28 knots
Speed (four engines):	15.57 knots
Fuel Consumption Open Water:	30m^3
Fuel Consumption Heavy Ice:	90m^3

Deck Machinery

Tugger Winches:	2 x 15-tonne pull
Capstans:	2 x 10-tonne pull
Towing & Work Winches:	2 Double-Drum Towing/Anchor-Handling Winches—Van Der Gleseen
Deck Cranes:	2 x 5-ton SWL Hagglund Wartsila

Life-saving Units

Life Boat:	40-person Watercraft Model 7.8m
Rescue Boat:	Lucas Model 700D

2 PROJECT PLAN (TASK 1)

The project plan for this work followed the six tasks identified in the Statement of Work which is presented in Appendix A. These were:

Task 1: Planning and System Design
Task 2: Software Development
Task 3: Instrumentation Design, Procurement and Installation
Task 4: Full Scale Tests
Task 5: Analysis of Full Scale Data
Task 6: Prepare and Present Final Report

The schedule for carrying out these tasks is included in Appendix A.

Due to the short lead time for the instrumentation design and installation as well as the unique nature of the project much of the work involved in the first three tasks had to be performed concurrently. Much of the detail of the data acquisition and data collection philosophy to be used had been well worked out by Arctec Canada Limted in previous similar projects, as had the requirements for keeping test logs, manual documentation to be kept and the ice observations and measurements to be made. As a result project planning focused upon the parameters to be measured, the sensors needed to measure them and the techniques required to process and analyse the data.

The results of the system design activity are presented in the sections of this report entitled "Software Development" and "Instrumentation Installation and Calibration". The data collection activity is described in the section entitled "Full Scale Tests". The methodology developed for analysing the data is presented together with the results of each specific type of investigation in the section entitled "Analysis of Data".

3 SOFTWARE DEVELOPMENT (TASK 2)

Software development for data acquisition and real time analysis was performed during the instrumentation installation and full scale tests, due to time restrictions. The software performed well and data collection began July 27, 1986.

The data acquisition software performed the following:

- Continuous sampling of 61 channels of data at 500 readings /sec/channel.
- Event detection by excursion of selected channels by a specified value.
- Storage of a 6.25 second window of data (3 seconds prior to event detection and 3.25 seconds after).
- Capability of reducing scan rate for ramming tests and calibration tests.

The real time analysis software performed the following:

- Animated plots of the longitudinal stern bearing strain distribution.
- Animated plots of the circumferential stern bearing strain distribution.
- Time history plots of all sensor outputs.
- Re-scaling of all plots.
- Plots of the movement of the shaft at the stern tube seal.
- Time history plots of shaft torque, thrust, and bending.
- Time history plots of shaft intermediate bearing loads.

Software was developed for the post test analysis to perform the following:

- Calculation of Max/Min/Mean values of all of the data.
- Histogram plotting.
- Digital Filtering of data.
- Animated view of compressive bearing load distribution.
- Report output for selected data.
- Calculation and plots of shaft accelerations.
- Calculation and plots of intermediate shaft bearing loads (vertical and transverse)
- Direction of load on shaft intermediate bearing.

A menu flow chart for the data acquisition and analysis program is illustrated in Figure 3.1. Appendix F contains the program listing.

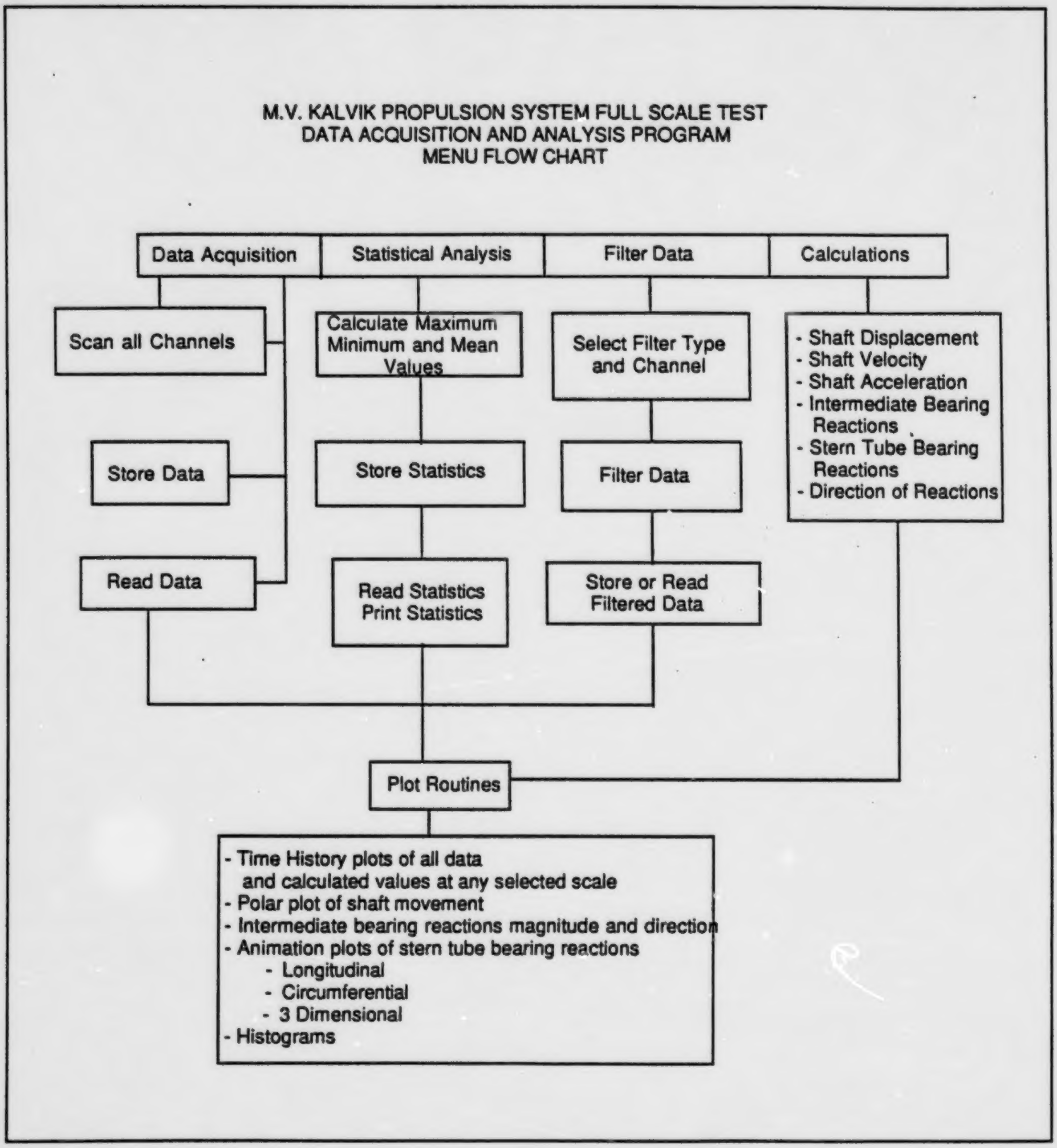

M.V. KALVIK PROPULSION SYSTEM FULL SCALE TEST
DATA ACQUISITION AND ANALYSIS PROGRAM
MENU FLOW CHART
Data Acquisition
Statistical Analysis
Filter Data
Calculations
Scan all Channels
Calculate Maximum Minimum and Mean Values
Select Filter Type and Channel
- Shaft Displacement
- Shaft Velocity
- Shaft Acceleration
- Intermediate Bearing Reactions
- Stern Tube Bearing Reactions
- Direction of Reactions
Store Data
Store Statistics
Filter Data
Read Data
Read Statistics Print Statistics
Store or Read Filtered Data
Plot Routines
- Time History plots of all data and calculated values at any selected scale
- Polar plot of shaft movement
- Intermediate bearing reactions magnitude and direction
- Animation plots of stern tube bearing reactions
- Longitudinal
- Circumferential
- 3 Dimensional
- Histograms

Figure 3.1 Software Menu Flow Chart

4. INSTRUMENTATION DESIGN / INSTALLATION / CALIBRATION (TASK 3)

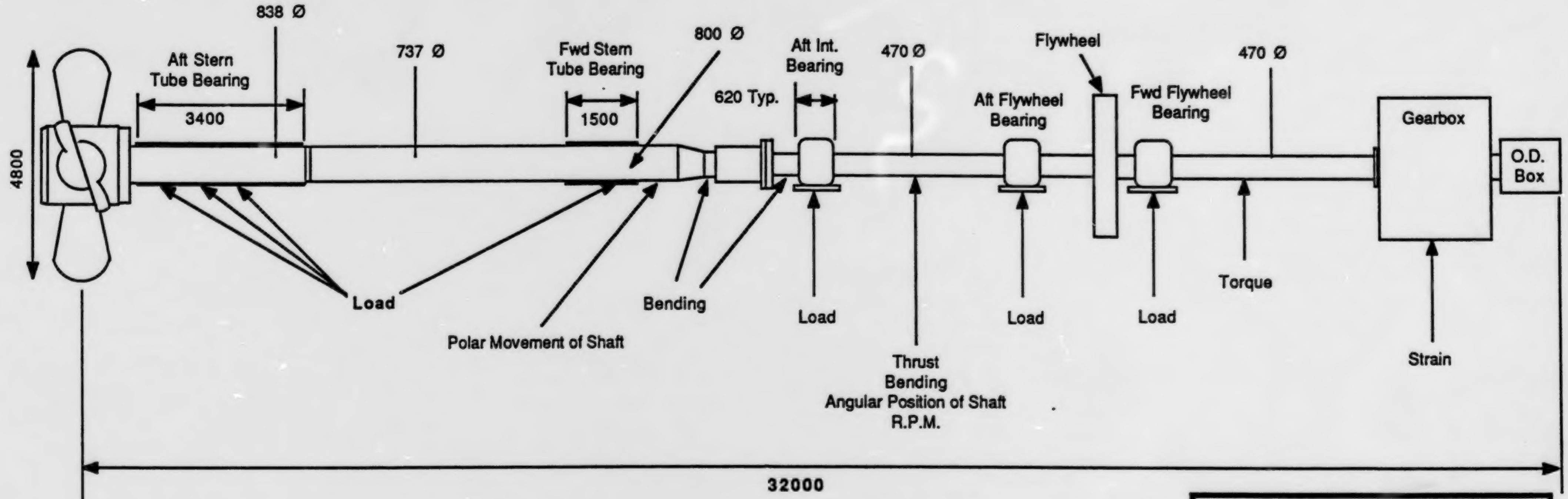
The instrumentation system employed on the M.V. Kalvik starboard propulsion train was designed to provide complete engineering values on the response of the system to ice forces induced on the propeller blades and the hull during icebreaking operations. Measurements to determine the loads in the stern tube bearings and propeller blade forces were regarded as a priority.

4.1 Shafting / Intermediate Bearings / Structural Instrumentation

Figure 4.1.1 illustrates the location and the type of measurements recorded on the starboard propulsion system during the full scale tests on the M.V. Kalvik. Figure 4.1.2 illustrates the location of accelerometers and the longitudinal deck bending gauges installed.

Standard strain gauge techniques were used on all strain measurements. Rotating machinery signals (shaft thrust, shaft bending, etc.) were transmitted via standard FM telemetry systems. The machinery signals were recorded from the existing outputs on the vessel. Further details of the instrumentation and the method of analysis for each signal are provided in sections pertaining to the analysis of the measurements taken.

Calibrations of all sensors were conducted in the vessel and the details of these are provided in Appendix D. Field notes describing the installation are also in Appendix D.

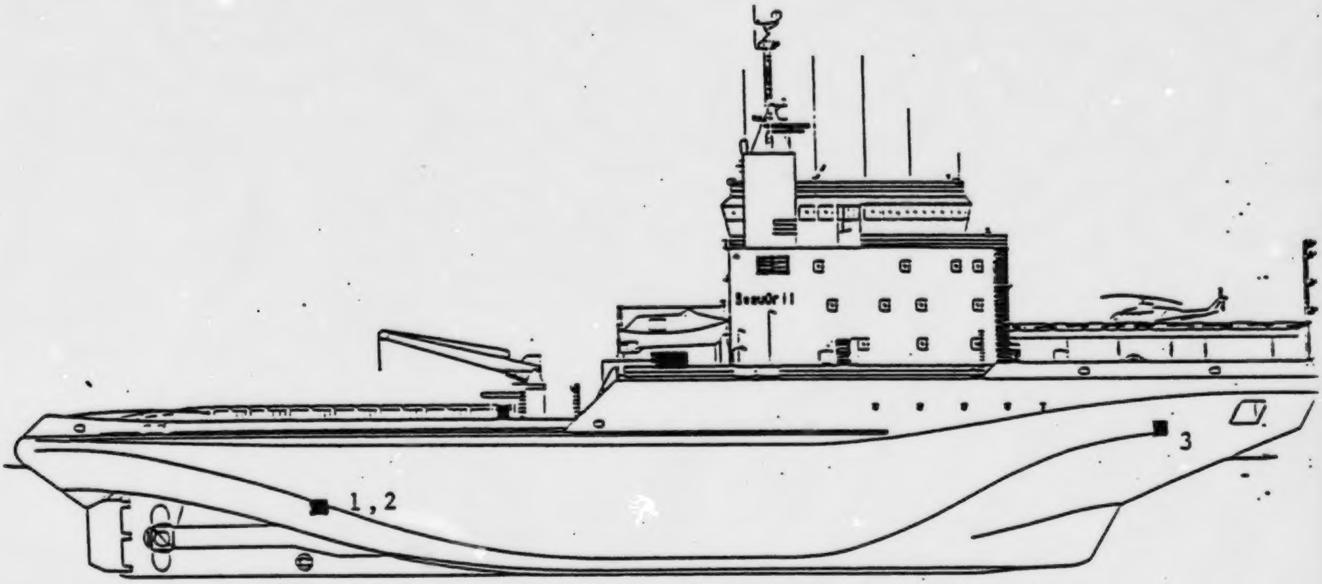


Scale 1:100

Dimensions in mm

Notes: Other measurements included
- **Rudder Angle**
- **Rudder Stock Torque**
- **Fuel Rack Position**

Figure 4.1.1 Starboard Shafting Instrumentation



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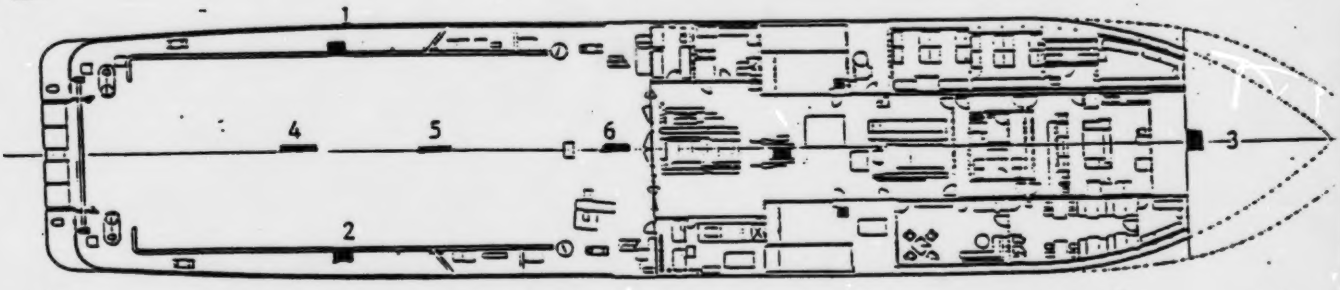


MAIN DECK

Figure 4.1.2 Location of Accelerometers and Deck Bending Gauges

1,2,3 - Vertical Accelerometers
4 - Deck Bending Gauge Frame 26
5 - Deck Bending Gauge Frame 43
6 - Deck Bending Gauge Frame 68

4.2. Stern Tube Bearing Instrumentation / Installation / Calibration

Introduction / Summary

To design safer and more reliable stern tube bearings it is essential to determine the magnitude and distribution of dynamic loads on the bearings while icebreaking. To our knowledge, due to the difficulty of instrumenting stern tube bearings, the direct measurements of full scale bearing forces have not been undertaken before. This section describes the unique instrumentation employed to determine the dynamic loads on the starboard stern tube bearings of the M.V. Kalvik.

The stern tube bearings of the M.V. Kalvik are manufactured by The Johnson Rubber Company of Middlefield, Ohio. These bearings have the following particulars:

Type of Material	Rubber	
Forward Bearing		
Length (1 section)	1524.	mm
Diameter (12 staves spaced equally)	802.	mm
Aft Bearing		
Length (2 sections each 1.7 m long)	3400.	mm
Diameter (12 staves spaced equally)	840.	mm
Thickness	50.	mm
Water Groove Depth (12 grooves)	12.	mm
Water Flow Rate	80.	gpm
Static Load	276.kPa (40 psi)	
Radial Clearance	0.75 - 1.1 mm	

Because of this unusual application of strain gauge technology in a rubber material, laboratory tests were conducted to test the reliability of the strain gauge installation, determine the properties of the bearing material, and record the response of the installed strain gauge. The tests indicated that the strain gauge installation was satisfactory; therefore, a total of 33 strain gauges were installed in the back side of a new set of rubber stave bearings. The gauges were distributed in the bearings such that the circumferential and longitudinal distribution of load could be estimated.

It was found that the elastic modulus of the rubber material increases with both loading rate and longitudinal compression (the bearings are compressed longitudinally when installed in the vessel). For the loading rates measured and the existing longitudinal compression in the bearings during the full scale tests the following was determined:

Forward bearing	Elastic Modulus=105 MPa. (15,200 psi)
Aft bearing	Elastic Modulus=100 MPa. (14,500 psi)

Two calibration equations were determined also, one for low strains (less than 0.0015) and one for high strains (greater than 0.0015):

1. measured strain < 0.0015 Pressure= (measured strain)(320) [MPa.]
2. measured strain > 0.0015 Pressure=.5+(measured strain-0.0015)(835) [MPa.]

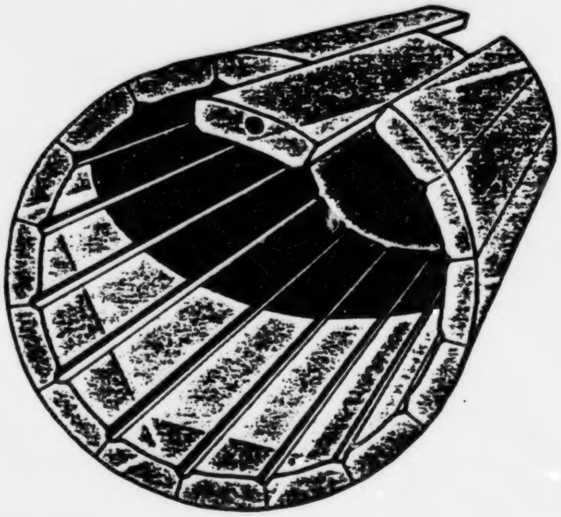


Figure 4.2.1 3-D Representation of Complete Stern Tube Bearing

Strain Gauge Installation in Rubber Bearing Stave

Strain gauges were installed in the rubber bearing staves to measure compressive loads as shown in Figure 4.2.2. A 19 x 19 mm by 12 mm deep recess was machined in the back side of the rubber stave, and a 6 x 6 mm deep groove was machined from this recess to the stave end. In the recess a vertical wall parallel to the end of the stave was prepared by sanding and cleaning. A strain gauge was then glued on to the wall and clamped until dry. Double jacketed etched teflon wire was then attached to the strain gauge and the wire run out along the machined groove. The recess and approximately 50 mm of the groove was then filled and sealed with special waterproofing material. The remainder of the groove was filled with silicone rubber.

Laboratory Testing

Two periods of laboratory testing on an instrumented sample of the rubber bearing were conducted. The first session was conducted prior to the field tests and the second after returning from the full scale tests.

The following were the objectives of the first session of laboratory testing:

1) Establish the durability of the installed strain gauge under expected radial and longitudinal compression.

2) Ensure that the gauge could withstand high dynamic loads and remain waterproof under a prolonged pressurized water environment (as would be the case in the actual bearing to be installed).

The gauge responded well to dynamic loads with good repeatability in results. The gauge was not damaged when exposed to water or under severe longitudinal compression. Therefore, the strain gauge installation technique was approved and employed on a new set of bearings, provided by The Johnson Rubber Company, that were installed in the vessel during its drydock in August 1986.

After the full scale tests were conducted a second set of laboratory tests were performed on the test piece of rubber bearing to determine the following:

1) Determine the effect of longitudinal compression (confinement) and loading rate on the material properties of the bearing.

2) The properties of the rubber material and evaluation of calibration factors.

3) Determine the relationship between the strain of the bearing to the strain measured by the strain gauge.

A test apparatus for simulating the condition of the bearing in the vessel was constructed. The test piece was confined circumferentially and compressed longitudinally as was the bearing in the vessel. Loading rates and the maximum measured strain were determined from the full scale data collected. Similar loads were applied to the test piece of bearing material and the corresponding response from the gauge was measured.

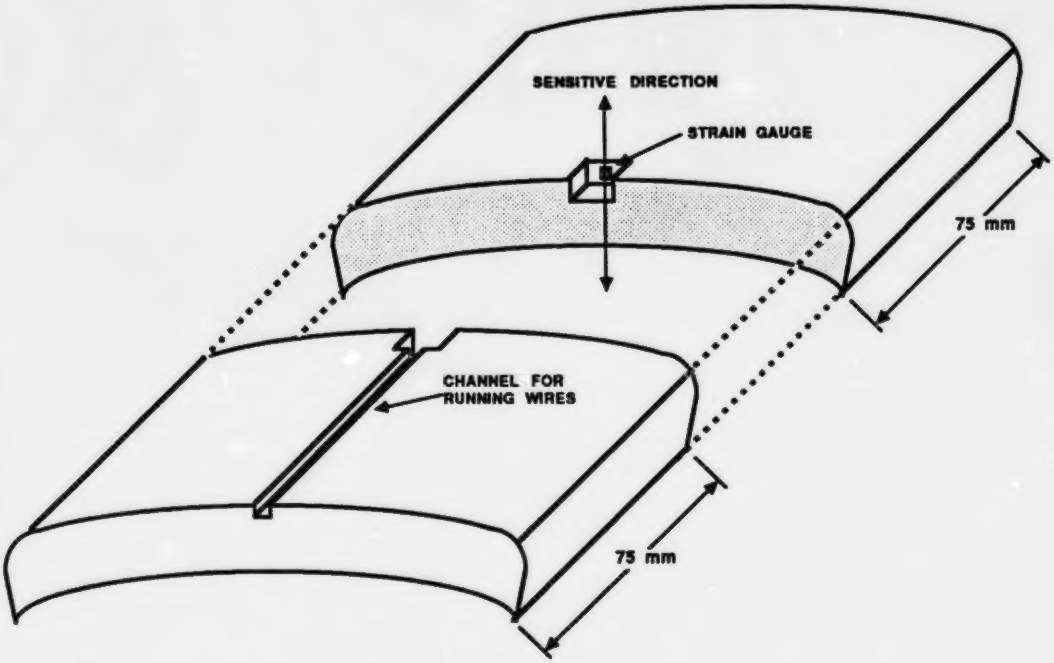


Figure 4.2.2

Bearing Stave Sample Used as Test Specimen
Showing Typical Gauge Installation in Milled "Pocket"

It was determined that the bearing material had an elastic modulus that is highly dependent on longitudinal compression and weakly dependent on loading rate. Under the same loading rate the elastic modulus of the bearing increases with longitudinally compression. The modulus changes from 74 MPa at 0% longitudinal compression to 98 MPa at 2.2% longitudinal compression for a loading rate of 6.8 MPa/sec., as shown in Figure 4.2.3. Figure 4.2.3 illustrates the relationship between elastic modulus and loading rate. At a longitudinal compression of 2.2%, the elastic modulus increases from 98 MPa to 115 MPa (15%) when the loading rate is increased from 6.8 MPa/sec. to 136 MPa/sec., (200%).

A detailed explanation of all laboratory tests conducted can be found in Appendix B and pictures of the specimen and test equipment can be found in Appendix E.

Calibration

In the laboratory it was found that the strain measured by the strain gauge was only 1/5 - 1/10 of the actual strain occurring. This can be attributed to the effect of milling a recess for the strain gauge and then filling the recess with a potting compound of reduced stiffness which changes the stress field in the sample. Despite the fact the strain measured by the bearing strain gauge does not correlate directly with actual strain, the stress vs. strain curves does show constant, repeatable characteristics for the same loading rate and longitudinal compression. Therefore, calibration factors can be calculated with confidence.

Figure 4.2.4 shows a typical stress vs strain curve for the bearing. The curve is represented by two straight lines, the slope of each line corresponding to a calibration factor. One calibration factor for strains less than 0.0015 and one for greater than 0.0015. Figure 4.2.5 shows how the the calibration factor varies with longitudinal compression and loading rate.

In the M.V. Kalvik, the aft stern tube bearing is compressed longitudinally by 1.1% and in the forward bearing by 1.25%. The typical measured rise time from no load to full load during an ice milling event was found to be approximately 25 milliseconds, with strains as high as 0.01. The calibration factor for this type of loading is between 820 and 850 MPa/strain as determined from Figure 4.2.5. From the laboratory data the average slope of the lower part of the stress vs strain curve is 320 MPa/strain. The equations for calculating the applied pressure at the strain gauge location are as follows:

1. measured strain < 0.0015 Pressure= (measured strain)(320) [MPa.]
2. measured strain > 0.0015 Pressure=.5+(measured strain-0.0015)(835) [MPa.]

Calibration tests were also performed in the installed instrumented stern tube bearing. The bearing was compressed using a hydraulic ram with a load cell in series with it. The applied load and the output of the strain gauge were measured simultaneously. Figure 4.2.6 shows a plot of applied pressure vs measured strain. The values of the measured in-situ calibration factor range from 400 to 900 MPa/strain which is in good agreement with the values obtained in the second set of laboratory tests.

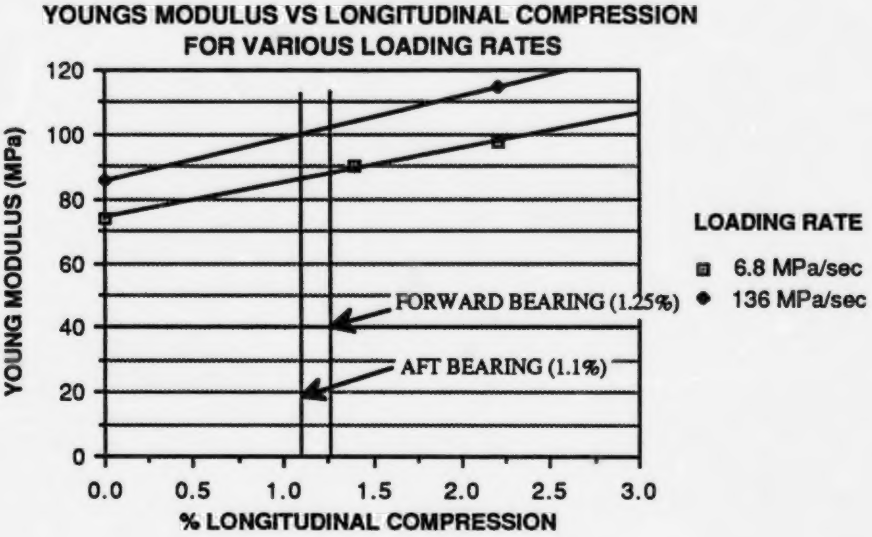


Figure 4.2.3 Youngs Modulus vs Longitudinal Compression for Various Loading Rates

LARGE PLATEN - 2% LONG. COMP. - 136 MPa/s LOADING RATE
TEST NUMBER 1   RUN NUMBER 15

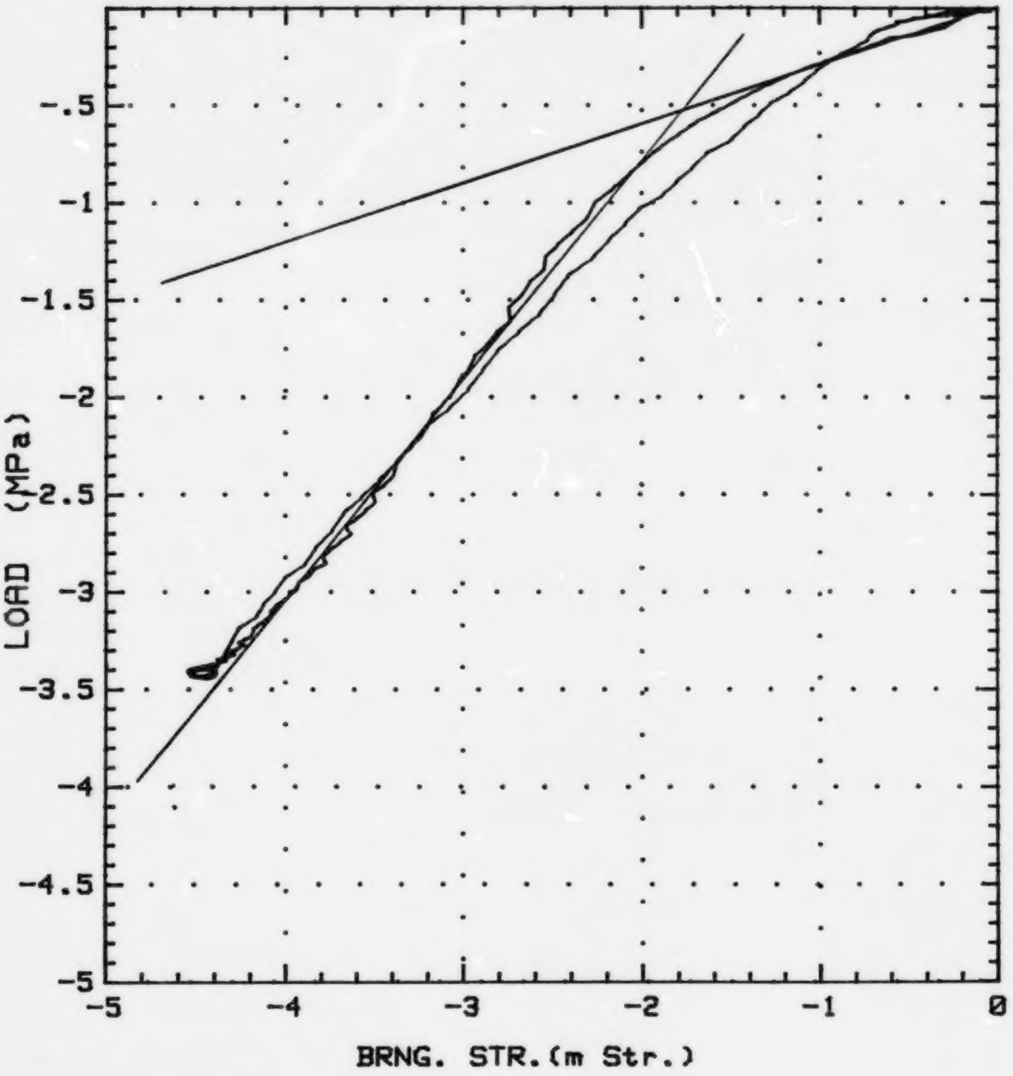


Figure 4.2.4 Typical Load vs Strain Measured by the Strain Gauge

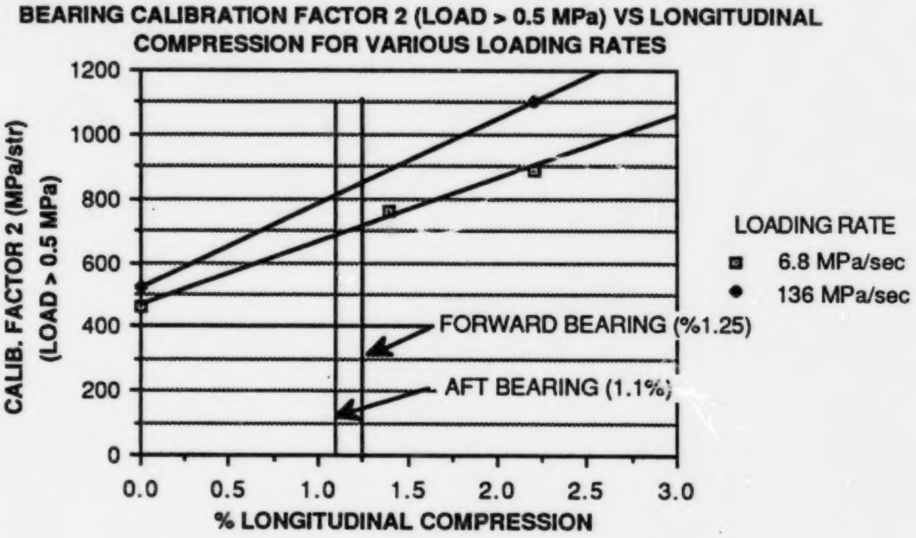


Figure 4.2.5 Bearing Calibration Factor 2 vs Longitudinal Compression for Various Loading Rates

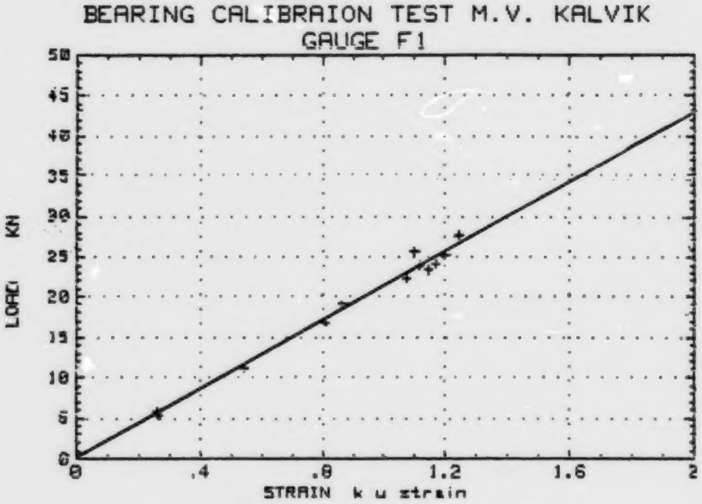


Figure 4.2.6 In-situ Calibration of Bearing Slave

Installation of Instrumented Rubber Bearing Staves in Stern Tube

The installation of the instrumented bearings was performed while the ship was in drydock, after the propeller shaft and the old bearings had been removed. Holes were drilled in the brass retaining ring of the forward and aft bearings to permit the wires to pass from the backside of the rubber staves into the stern tube (Figure 4.2.7). To run the wires out of the stern tube and into the ship, a hole was cut through the 50 mm thick stern tube at the 12 o'clock position forward of frame 27 inside a watertight compartment. A collar was welded into the hole to provide stress relief and a smooth surface to pass wires over. A 200 mm diameter steel tube was welded on the outside around the hole in the stern tube to form a watertight coffer dam as shown in Figure 4.2.8. A steel channel was welded longitudinally to the top of the stern tube, extending from the forward stern tube bearing to the aft bearing and intersecting the stern tube penetration, to act as a collecting duct for wires leading out of the bearings, as illustrated in Figure 4.2.9.

The stern tube was cleaned in preparation for the installation of the instrumented rubber bearings. The forward stern tube bearing was installed first beginning with the bottom stave, and adding staves circumferentially on either side of the bottom one. The strain gauge wires were fed through the holes in the compression ring as each stave was installed. A plywood cylinder was placed in the tube to act as temporary support for the upper half of the bearing. The last of the twelve staves to be installed was the top dead centre one. This stave had to be physically hammered in with a large sledge hammer to provide the circumferential compression required in the bearing. The compression ring was installed and provided a longitudinal compression of 1.25%.

The installation of the aft stern tube bearing was more difficult. The aft stern tube bearing is composed of twenty-four staves, two longitudinal sets of twelve staves circumferentially spaced. The wires from the aft half of the bearing were set in the groove in the forward half of the bearing, the groove was filled with silicone and the forward and aft staves were slide into place in unison.

The wires coming from each bearing were bundled and fed through the steel channel and out through the coffer dam. The coffer dam was filled with a potting compound and the lid sealed. The individual strain gauges were then connected to the data acquisition system.

The system proved reliable with only a few of the highly loaded gauges failing from fatigue. The area around the penetration of the stern tube was inspected after the tests and no leakage or any sign of damage could be found.

Bearing Temperature Measurements

The load on the rubber stave bearings during ice propeller interaction was extremely short in duration (0.04 seconds). Engineering calculations indicated that temperature changes due to this type of loading would be insignificant and could not be measured accurately. Therefore, because of time constraints, bearing temperature measurements were not recorded.

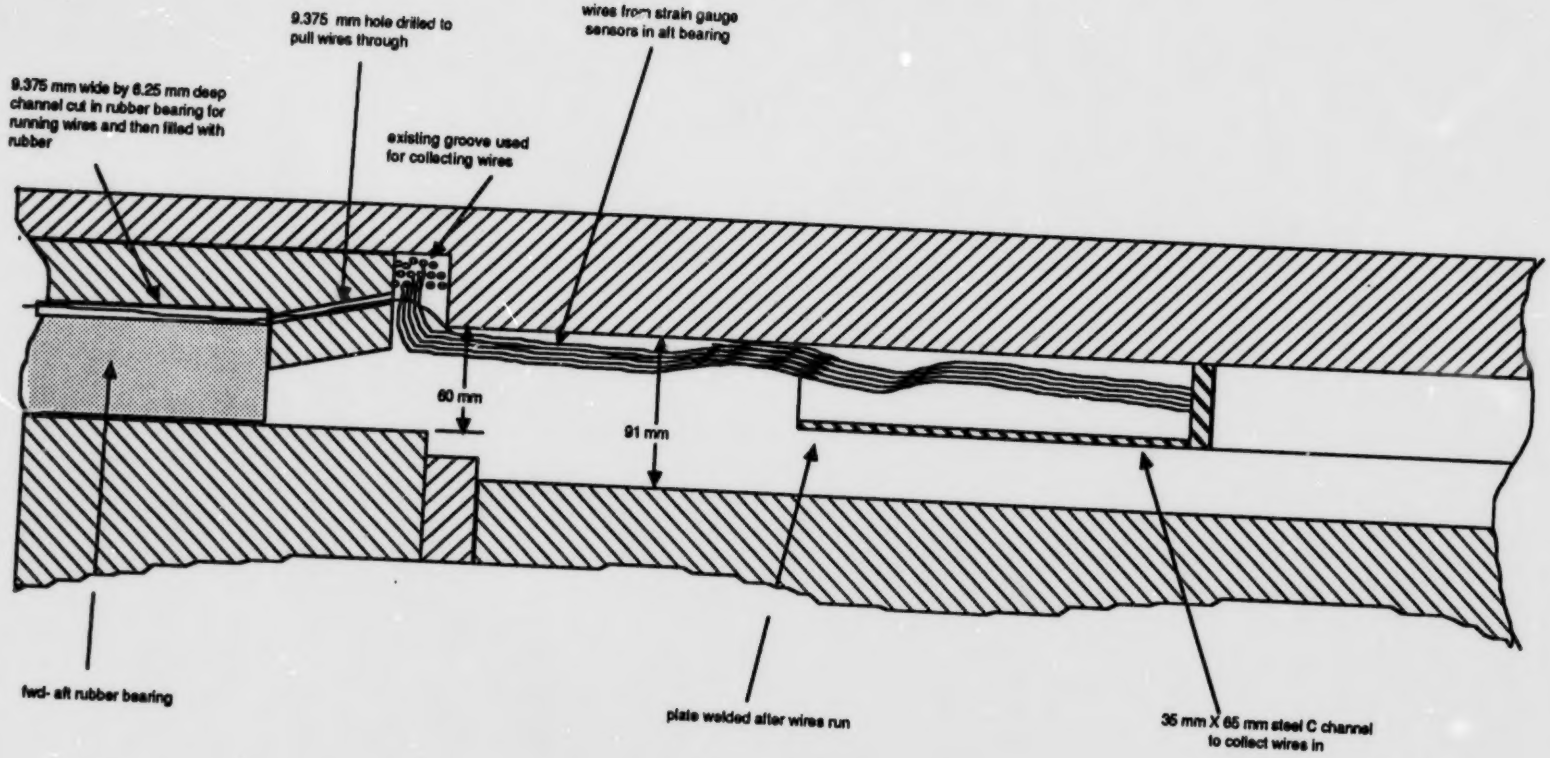

9.375 mm hole drilled to pull wires through
wires from strain gauge sensors in aft bearing
9.375 mm wide by 6.25 mm deep channel cut in rubber bearing for running wires and then filled with rubber
existing groove used for collecting wires
60 mm
91 mm
fwd- aft rubber bearing
plate welded after wires run
35 mm X 65 mm steel C channel to collect wires in

Figure 4.2.7

Longitudinal Cross Section Showing Sensor Wires Passing Out of Aft Stern Tube Bearing

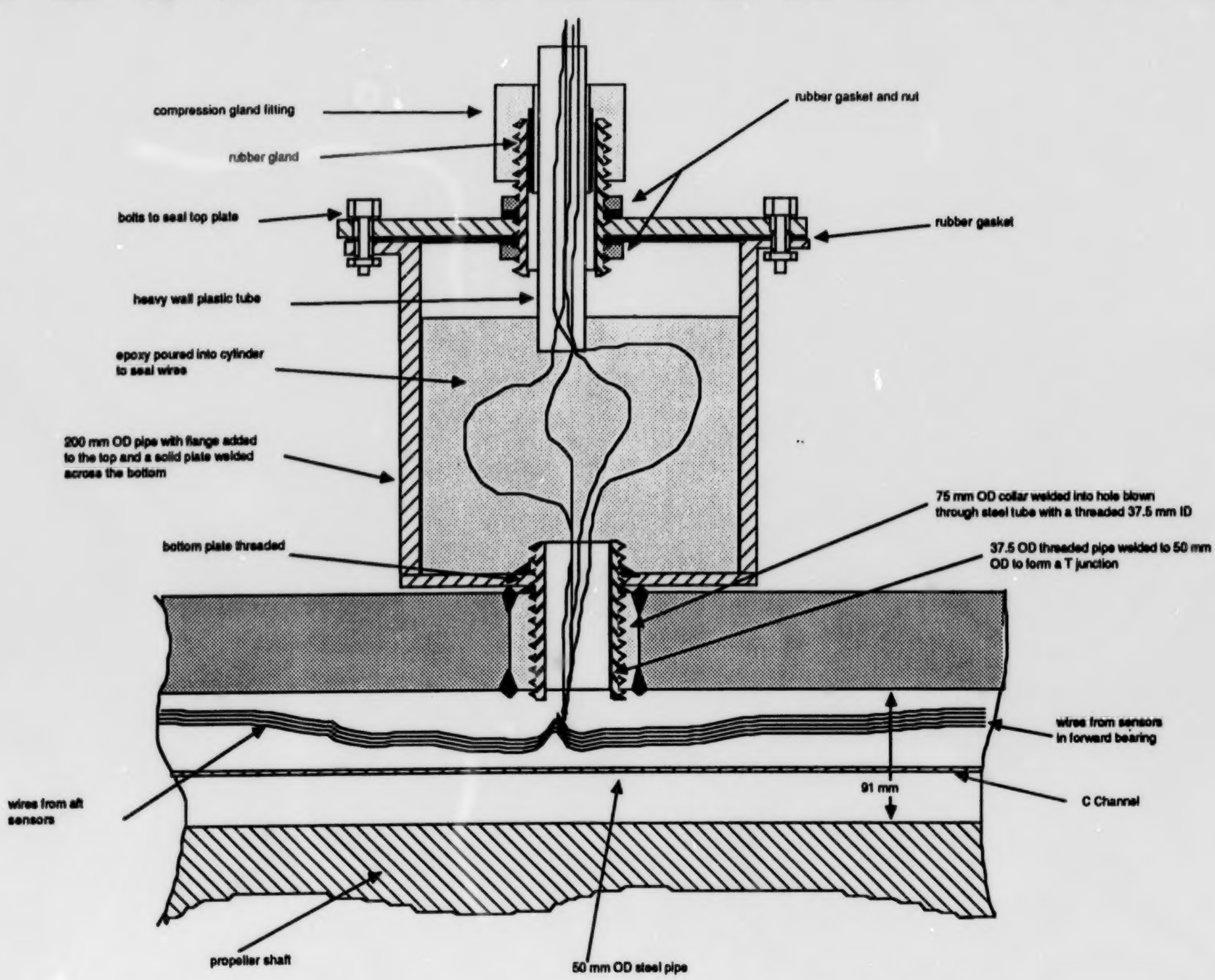

compression gland fitting
rubber gland
bolts to seal top plate
heavy wall plastic tube
epoxy poured into cylinder to seal wires
200 mm OD pipe with flange added to the top and a solid plate welded across the bottom
bottom plate threaded
rubber gasket and nut
rubber gasket
75 mm OD collar welded into hole blown through steel tube with a threaded 37.5 mm ID
37.5 OD threaded pipe welded to 50 mm OD to form a T junction
wires from sensors in forward bearing
C Channel
91 mm
wires from aft sensors
propeller shaft
50 mm OD steel pipe

Figure 4.2.8 Longitudinal Cross Section of Stern Tube Penetration

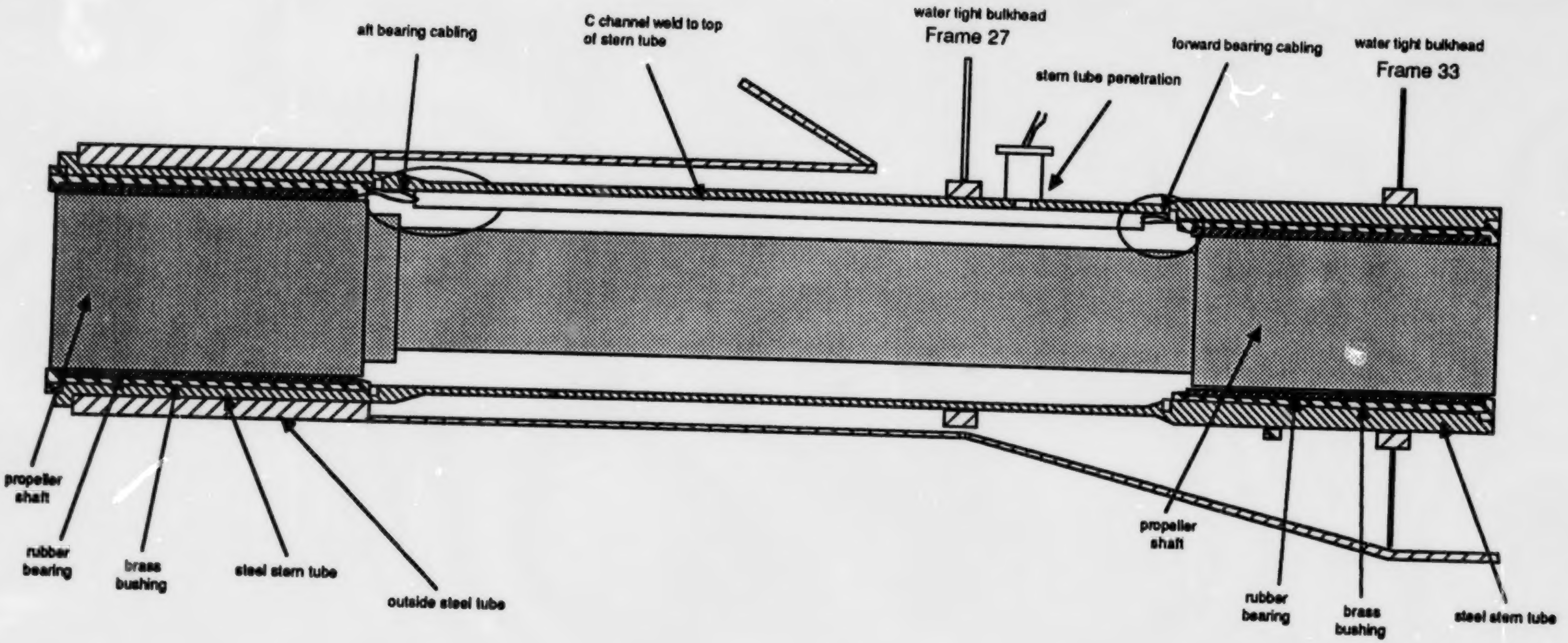


Figure 4.2.9 Longitudinal Cross Section Through Propeller Shaft

4.3 Data Acquisition

The data acquisition system used is illustrated in block form in Figure 4.3.1. This system has been developed over the last four years from previous full scale tests conducted by Arctec Canada Limited personnel and uses the most advanced and reliable field equipment available. Each signal was continuously sampled at 500 readings/second. An ice/propeller interaction event duration can vary from 0.5 to 5.0 seconds but is typically 3 to 4 seconds long. An event was detected by the excursion of selected readings by a specified amount (e.g., shaft torque greater than 125% of MCR torque). A window of data 6.25 seconds long, 3 seconds before the event was detected and 3.25 seconds after, was stored on a magnetic floppy disk (greater than 190,000 readings per event).

During the ridge ramming tests each sensor was sampled at 100 readings/second for 31.25 seconds. The collection of data was triggered manually prior to impacting a heavy ice feature.

Table 4.3.1 lists the signals recorded during the full scale tests.

Table 4.3.1 Signals Recorded

NO.	DESCRIPTION
33	Strain Gauges on Rubber Staves
4	Hull Bending Gauges
2	Gear Case Bending Gauges
6	Intermediate Bearing Foundation Gauges
3	Shaft Bending Gauges
1	Shaft Torque Gauges
1	Shaft Thrust Gauges
1	Shaft Speed and Orientation
1	Propeller Pitch
1	Rudder Angle
1	Rudder Torque
3	Hull Accelerations
1	Ship Speed
2	Shaft Movement Probes
1	Engine Fuel Rack
61	Total

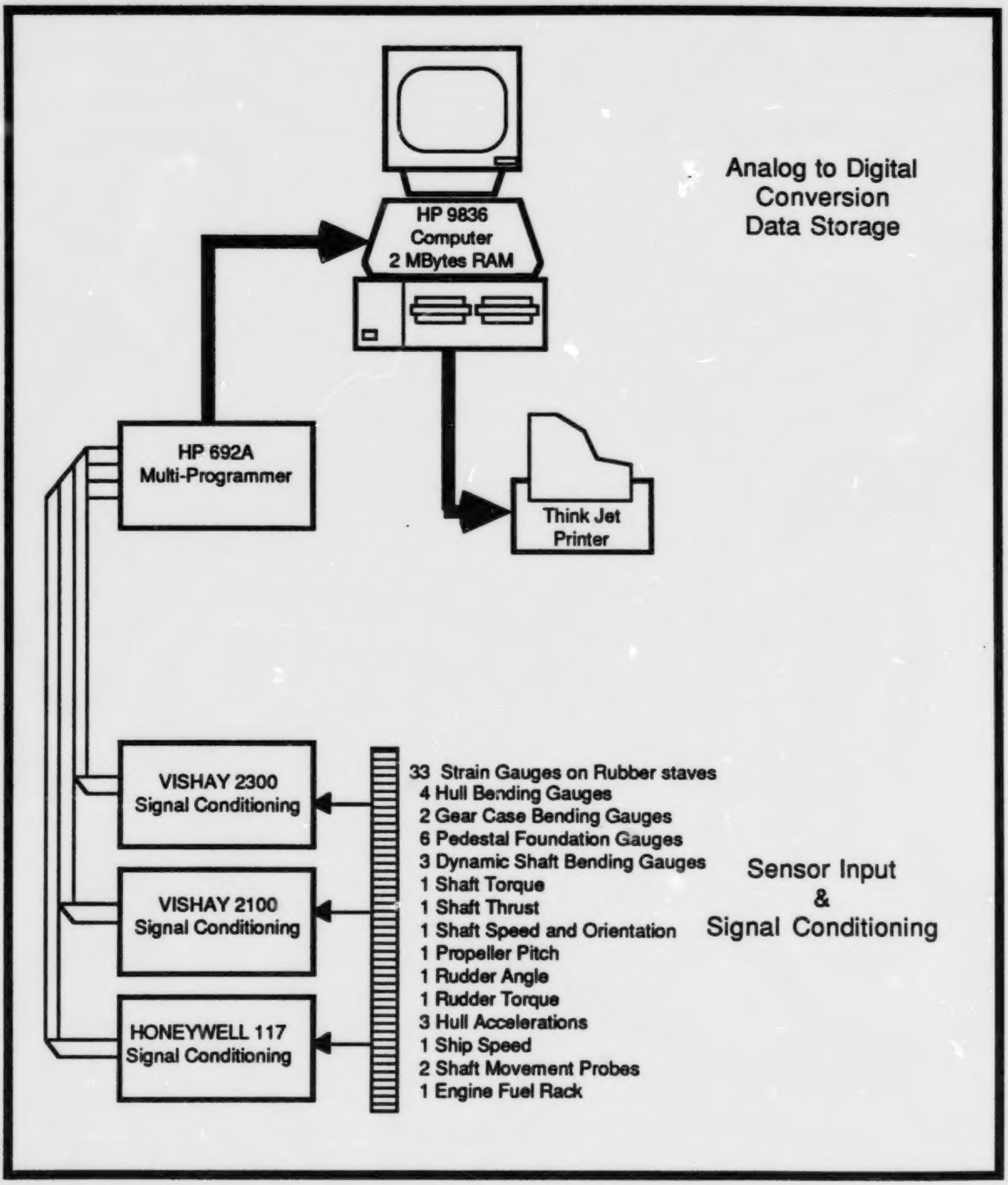


Figure 4.3.1 Data Acquisition System Block Diagram

5. FULL SCALE TESTS (TASK 4)

The M.V. Kalvik was drydocked in Arctic Transportation Limited's floating dock, at Tuktoyaktuk, N.W.T. on August 6, 1986. The ship repair was completed by August 21, 1986, and the vessel was chartered by the Canadian Coast Guard on August 26, 1986. The M.V. Kalvik proceeded to Resolute Bay, N.W.T., through the Prince of Wales Strait as shown in Figure 5.1. Heavy ice conditions were encountered as the vessel entered Viscount Melville Sound. Repeated ramming through multi-year ice and heavy second year ice was required.

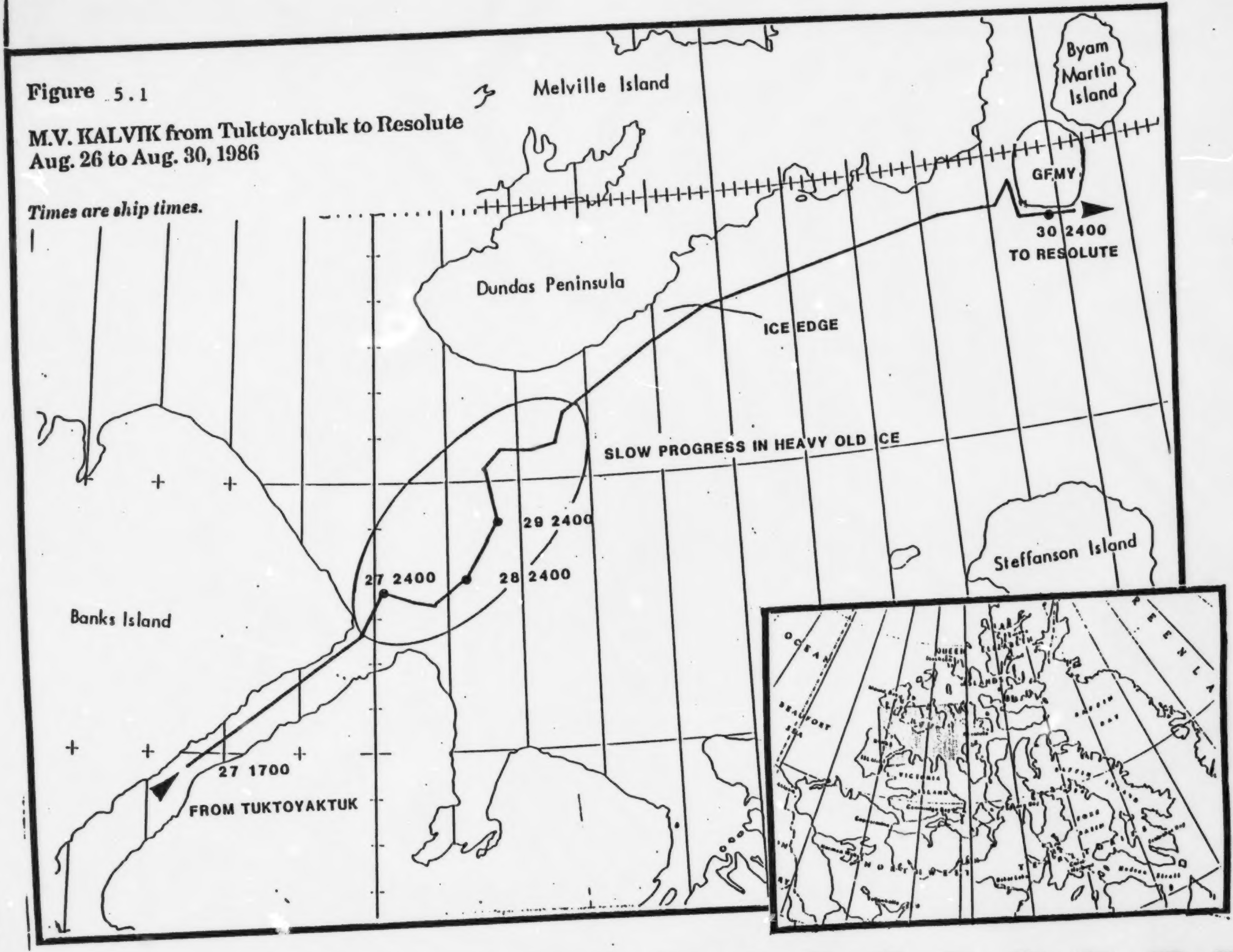
Upon arriving in Resolute Bay (August 31, 1986) the M.V. Kalvik joined the CGGS John A. MacDonald. Performance tests on the two vessels were conducted from September 2, 1986 to September 13, 1986. The vessels operated in second year and multi-year ice floes. Open water trials were conducted on September 13, 1986. The M.V. Kalvik returned to the Beaufort Sea near Tuktoyaktuk, N.W.T. on September 15, 1986. The John A. MacDonald returned to Resolute Bay, N.W.T. to continue its duties for the Canadian Coast Guard.

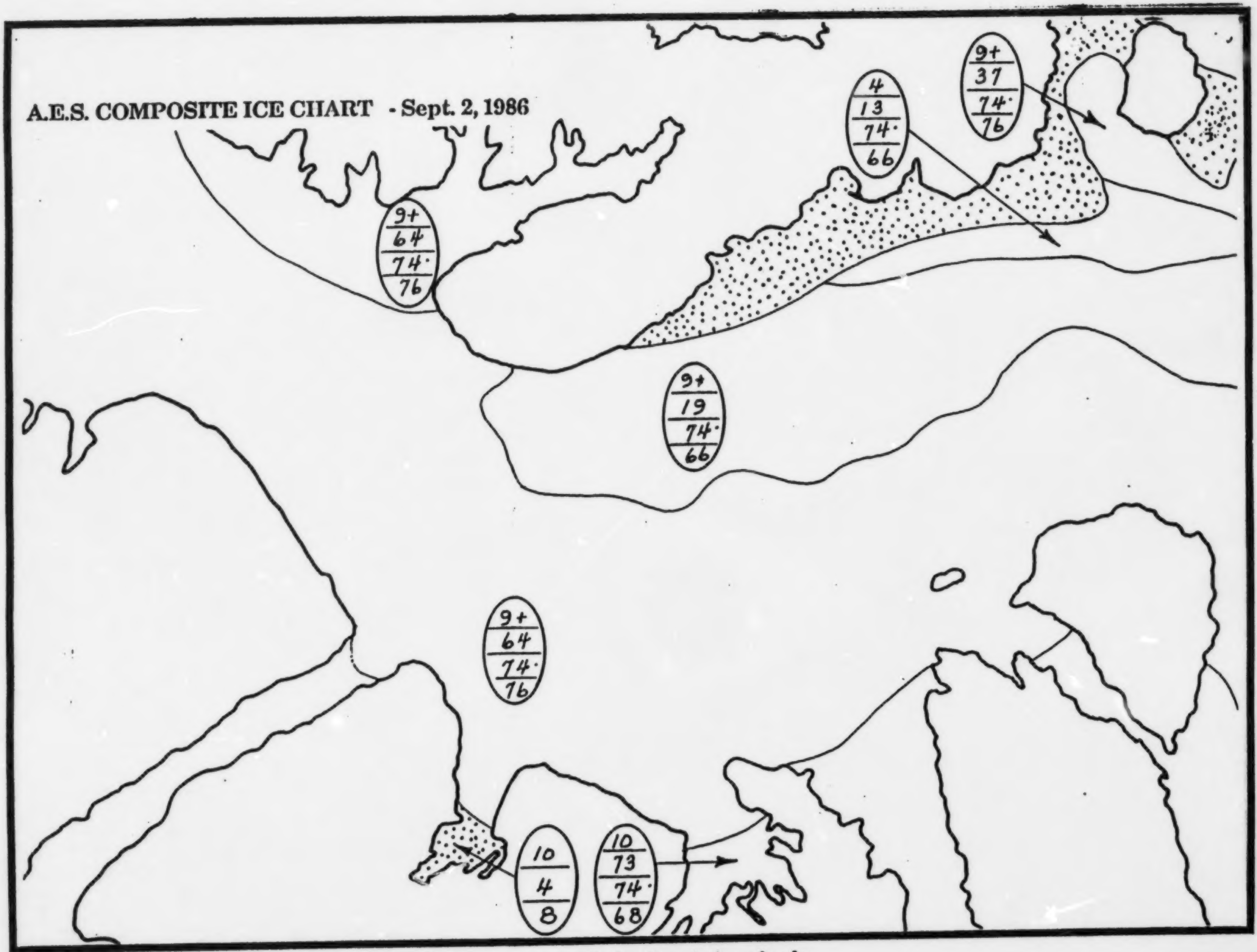
Figure 5.2 shows the voyage and trial locations from September 3 to September 13, 1986. An overlay of the ice conditions on September 2, 1986 is included.

Figure 5.1

M.V. KALVIK from Tuktoyaktuk to Resolute
Aug. 26 to Aug. 30, 1986

Times are ship times.





A.E.S. COMPOSITE ICE CHART - Sept. 2, 1986

Note: Ice conditions reported using A.E.S. "Egg Code" See appendix for description of code.

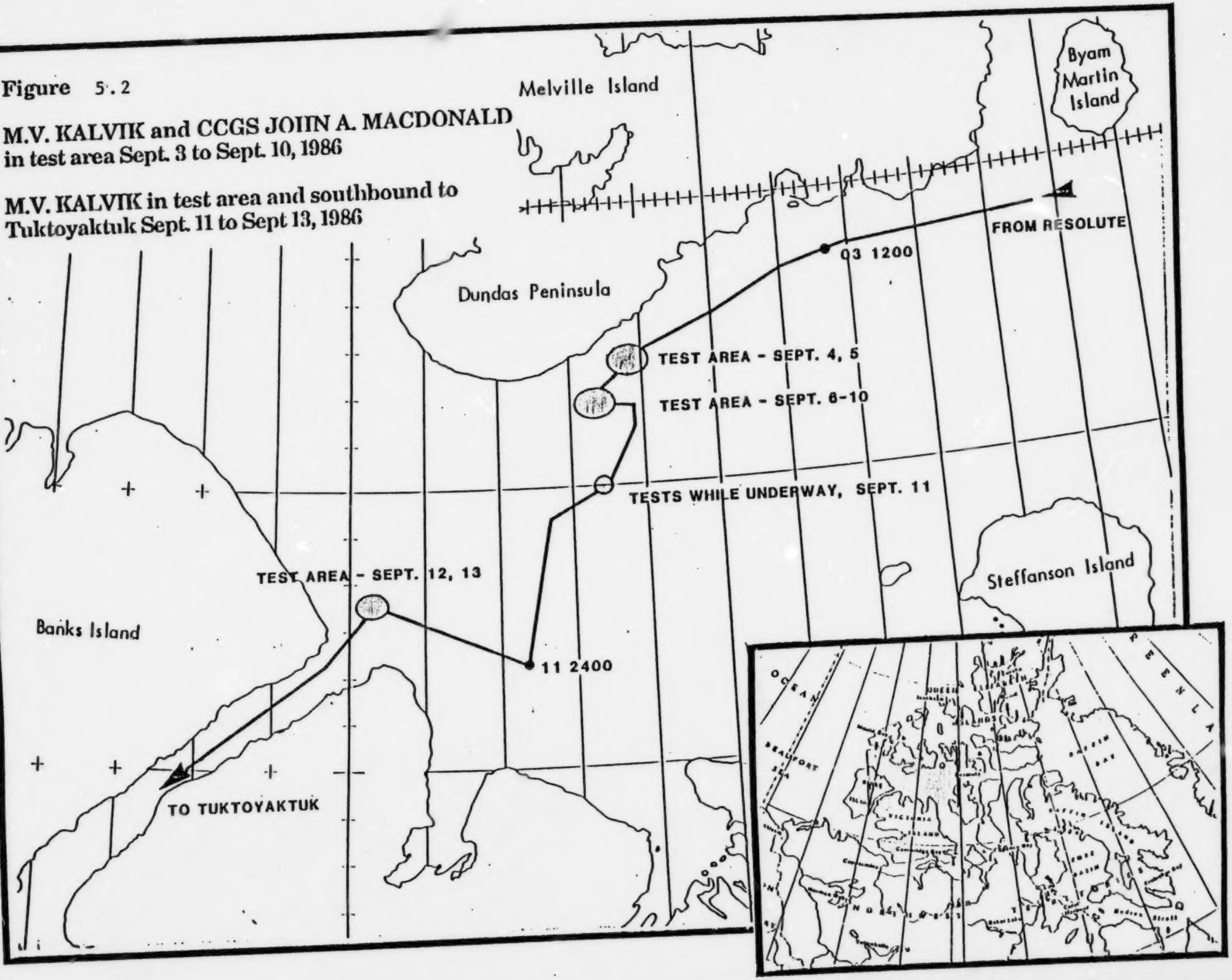


Figure 5.2

M.V. KALVIK and CCGS JOHN A. MACDONALD in test area Sept. 3 to Sept. 10, 1986

M.V. KALVIK in test area and southbound to Tuktoyaktuk Sept. 11 to Sept 13, 1986

5.1 Data Collected

Data was collected for the duration of the entire voyage. Sixty-one signals were recorded during each event. A total of ninety-four data disks were recorded, one disk for each event:

- 43 ice propeller events were recorded during the transit to Resolute
- 29 ice propeller events during the performance trials
- 11 open water
- 2 while the propeller was stuck in heavy multi-year ice
- 2 Bollard Push events
- 7 Ramming a multi-year ice ridge

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Table 5.1.1 lists the signals recorded.

Table 5.1.1 Signals Recorded

NO.	DESCRIPTION
33	Strain Gauges on Rubber Staves
4	Hull Bending Gauges
2	Gear Case Bending Gauges
6	Intermediate Bearing Foundation Gauges
3	Shaft Bending Gauges
1	Shaft Torque Gauges
1	Shaft Thrust Gauges
1	Shaft Speed and Orientation
1	Propeller Pitch
1	Rudder Angle
1	Rudder Torque
3	Hull Accelerations
1	Ship Speed
2	Shaft Movement Probes
1	Engine Fuel Rack
61	Total

5.2 Ice Conditions and Ships Log

The following significant events occurred during the full scale tests on the M.V. Kalvik:

1. Starboard propeller stuck in ice (August 28, 1986 - 09:00) and shaft declutched. Instrumentation system was used to assess damage and assist in determining a solution to remove ice.

2. Shaft declutch:

- August 28, 1986 - 11:25	Starboard
- August 28, 1986 - 12:40	Port and Starboard
- August 28, 1986 - 13:20	Starboard
- August 29, 1986 - 10:38	Port and Starboard
- August 30, 1986 - 10:25	Starboard
- Sept. 11, 1986 - 11:00	Starboard

Table 5.2.1 lists the detailed events log. This log lists the following for each for each event:

- the event label
- the date and time
- the location of the ship
- the surrounding ice conditions
- the ship status
- observations or special comments relevant to the event.

The information is derived from the computer records for each event and the Bridge log of the M.V. Kalvik.

Table 5.2.1 EVENTS LOG

2452C EVENTS LOG

EVENT #	LABEL	DATE	TIME	LOCATION	ICE	SHIP STATUS	COMMENTS/
					CONDITIONS		OBSERVATIONS
1	O_ICE_1	27-Aug-86	19:37:42	73°10.8'N115°58.3'W	4/10 thk 1st yr, 1/10 med 1st yr,med/sml floes	enroute to Viscount Melville Sd	
2	O_ICE_2	27-Aug-86	20:11:08	73°21.4'N115°32.3'W	4/10 thk 1st yr, 1/10 med 1st yr,med/sml floes	enroute to Viscount Melville Sd	
3	O_ICE_3	27-Aug-86	20:16:08	73°21.4'N115°32.3'W	4/10 thk 1st yr, 1/10 med 1st yr,med/sml floes	enroute to Viscount Melville Sd	
4	O_ICE_4	27-Aug-86	20:24:44	73°21.4'N115°32.3'W	4/10 thk 1st yr, 1/10 med 1st yr,med/sml floes	enroute to Viscount Melville Sd	
5	O_ICE_5	27-Aug-86	20:34:04	73°21.4'N115°32.3'W	4/10 thk 1st yr, 1/10 med 1st yr,med/sml floes	enroute to Viscount Melville Sd	
6	O_ICE_6	27-Aug-86	-				*clock read failure*
7	O_ICE_7	27-Aug-86	23:53:05	73°28.4'N115°11.6'W	7/10 thk 1st yr, 2/10 old ice,vast floes	enroute to Viscount Melville Sd	
8	O_ICE_8	28-Aug-86	0:02:51	73°33'N114°28'W	10/10 old ice,vast floes	vessel enroute	
9	O_ICE_9	28-Aug-86	0:02:51	73°33'N114°28'W	10/10 old ice,vast floes	vessel enroute	
10	O_ICE_10	28-Aug-86	0:35:25	73°33'N114°28'W	10/10 old ice,vast floes	vessel enroute	
11	O_ICE_11	28-Aug-86	0:44:25	73°33'N114°28'W	10/10 old ice,vast floes	vessel enroute	
12	O_ICE_12	28-Aug-86	0:47:23	73°33'N114°28'W	10/10 old ice,vast floes	vessel enroute	
13	O_ICE_13	28-Aug-86	0:54:20	73°33'N114°28'W	10/10 old ice,vast floes	vessel enroute	
14	O_ICE_14	28-Aug-86	0:58:37	73°33'N114°28'W	10/10 old ice,vast floes	vessel enroute	
15	O_ICE_15	28-Aug-86	12:47:49	73°31.3'N114°03.7'W	10/10 old ice,vast floes	underway in heavy ice	Declutch M/Eng 3&4 @ 11:25
16	O_ICE_16	28-Aug-86	12:50:46	73°31.3'N114°03.7'W	10/10 old ice,vast floes	underway in heavy ice	Declutch Pt&Stbd O/load in heavy ice
17	O_ICE_17	28-Aug-86	12:53:34	73°31.3'N114°03.7'W	10/10 old ice,vast floes	underway in heavy ice	
18	O_ICE_18	28-Aug-86	12:58:17	73°31.3'N114°03.7'W	10/10 old ice,vast floes	underway in heavy ice	
19	O_ICE_19	28-Aug-86	13:39:37	73°31.3'N114°03.7'W	10/10 old ice,vast floes	underway in heavy ice	Declutch M/Eng O/Load in heavy ice
20	O_ICE_20	28-Aug-86	13:51:09	73°31.3'N114°03.7'W	10/10 old ice,vast floes	underway in heavy ice	
21	O_ICE_21	28-Aug-86	14:09:01	73°29.1'N113°54.7'W	10/10 old ice,vast floes	underway in ice	
22	O_ICE_22	28-Aug-86	14:29:35	73°29.1'N113°54.7'W	10/10 old ice,vast floes	underway in ice	
23	O_ICE_23	28-Aug-86	14:53:52	73°29.1'N113°54.7'W	10/10 old ice,vast floes	underway in ice	
24	O_ICE_24	28-Aug-86	14:59:54	73°29.1'N113°54.7'W	10/10 old ice,vast floes	underway in ice	
25	O_ICE_25	28-Aug-86	16:01:55	73°30.5'N113°51.9'W	10/10 old ice,vast floes	underway in ice	
26	O_ICE_26	28-Aug-86	16:04:36	73°30.5'N113°51.9'W	10/10 old ice,vast floes	underway in ice	
27	O_ICE_27	29-Aug-86	0:02:42	73°34.2'N113°41'W	10/10 old ice,vast floes	underway in ice	
28	O_ICE_28	29-Aug-86	-	73°34.5'N113°44.2'W	10/10 old ice,vast floes	underway in ice	*clock read failure*
29	O_ICE_29	29-Aug-86	2:16:38	73°34.5'N113°44.2'W	10/10 old ice,vast floes	underway in ice	
30	O_ICE_30	29-Aug-86	14:26:35	73°52.1'N113°44.9'W	10/10 old ice,vast floes	underway in ice	P & S M/Eng down due to O/torque
31	O_ICE_31	29-Aug-86	14:48:02	73°52.1'N113°44.9'W	10/10 old ice,vast floes	underway in ice	
32	O_ICE_32	29-Aug-86	15:09:04	73°52.3'N113°47.6'W	10/10 old ice,vast floes	underway in ice	
33	O_ICE_33	29-Aug-86	18:54:45	73°53.5'N113°46.5'W	10/10 old ice,vast floes	underway in ice	
34	O_ICE_34	29-Aug-86	19:28:20	73°53.5'N113°46.5'W	10/10 old ice,vast floes	underway in ice	
35	O_ICE_35	29-Aug-86	20:55:02	73°56.8'N113°34.5'W	10/10 old ice,vast floes	underway in ice	
36	O_ICE_36	29-Aug-86	21:13:54	73°56.8'N113°34.5'W	10/10 old ice,vast floes	underway in ice	
37	O_ICE_37	30-Aug-86	4:31:06	74°02.3'N113°29.9'W	10/10 old ice,vast floes	underway in ice	Star 1 dropped @ 0125
38	O_ICE_38	30-Aug-86	8:46:29	74°07.3'N112°56.8'W	10/10 thk 1st yr ice,vast floes	underway in ice	
39	O_ICE_39	30-Aug-86	11:43:47	74°15.8'N112°10.5'W	10/10 thk 1st yr ice,vast floes	underway in ice	Declutch @ 10:25 in heavy ice
40	O_ICE_40	30-Aug-86	13:15:47	74°43.8'N105°28.1'W	10/10 thk 1st yr ice,vast floes	underway in ice	Reached open water @ 13:50
41	O_ICE_41	31-Aug-86	0:39:54	74°18.5'N111°50.4'W	1/10 med 1st yr, 9/10 thn 1st yr ice	underway in ice	Reached open water @ 01:30
42	O_ICE_42	3-Sep-86	16:17:24	74°32.3'N111°09.0'W	2/10 old, 8/10 thk 1st yr ice,vast floes	cargo away & mobilize	
43	O_ICE_43	4-Sep-86	9:13:58	74°28'N111°24.6'W	1/10 old, 8/10 thk 1st yr ice,vast floes	underway prior to Arktos trials	

Table 5.2.1 Events Log (cont.)

EVENTS LOG							
EVENT #	LABEL	DATE	TIME	LOCATION	ICE CONDITIONS	SHIP STATUS	COMMENTS/ OBSERVATIONS
44	TEST_01	4-Sep-86	21:22:41	5 mi.S. Cp.Clarendon	2/10 old, 8/10 med 1st yr, vast floes	Ice party out	
45	TEST_02	4-Sep-86	21:25:39	5 mi.S. Cp.Clarendon	2/10 old, 8/10 med 1st yr, vast floes	Ice party out	
46	TEST_03	5-Sep-86	12:07:04	off Cp.Clarendon	2/10 old, 8/10 med 1st yr, vast floes	On ice trials	
47	TEST_04	5-Sep-86	12:18:20	off Cp.Clarendon	2/10 old, 8/10 med 1st yr, vast floes	On ice trials	
48	TEST_05	5-Sep-86	12:24:54	off Cp.Clarendon	2/10 old, 8/10 med 1st yr, vast floes	On ice trials	
49	TEST_06	5-Sep-86	13:00:29	off Cp.Clarendon	2/10 old, 8/10 med 1st yr, vast floes	On ice trials	
50	TEST_07	5-Sep-86	13:00:29	off Cp.Clarendon	2/10 old, 8/10 med 1st yr, vast floes	On ice trials	
51	TEST_08	5-Sep-86	13:21:15	off Cp.Clarendon	2/10 old, 8/10 med 1st yr, vast floes	On ice trials	
52	TEST_09	5-Sep-86	13:43:22	off Cp.Clarendon	2/10 old, 8/10 med 1st yr, vast floes	On ice trials.	
53	TEST_10	5-Sep-86	13:47:20	off Cp.Clarendon	2/10 old, 8/10 med 1st yr, vast floes	On ice trials	
54	TEST_11	5-Sep-86	17:18:04	off Cp.Clarendon	2/10 old, 8/10 med 1st yr, vast floes	Just prior to M/Eng shutdown	
55	TEST_12	5-Sep-86	19:12:46	off Cp.Clarendon	2/10 old, 8/10 med 1st yr, vast floes	On ice trials	
56	TEST_13	5-Sep-86	19:59:48	off Cp.Clarendon	2/10 old, 8/10 med 1st yr, vast floes	On ice trials	
57	TEST_14	6-Sep-86	9:18:20	71°18.3'N111°42.3'W	2/10 old, 8/10 med 1st yr, vast floes	On ice trials	
58	TEST_15	6-Sep-86	13:33:18	71°18.3'N111°42.3'W	10/10 grey, vast floes	On ice trials	
59	TEST_16	6-Sep-86	19:43:08	71°18.3'N111°42.3'W	10/10 grey, vast floes	On ice trials	
60	TEST_17	6-Sep-86	20:07:57	71°18.3'N111°42.3'W	10/10 med 1st yr, vast floes	On ice trials	
61	TEST_18	7-Sep-86	9:36:18	74°18'N111°39.4'W	2/10 old, 8/10 med 1st yr, vast floes	On ice trials	
62	TEST_19	7-Sep-86	10:43:10	74°18'N111°39.4'W	2/10 old, 8/10 med 1st yr, vast floes	On ice trials	
63	TEST_20	7-Sep-86	16:27:42	74°18'N111°39.4'W	2/10 old, 8/10 med 1st yr, vast floes	On ice trials	
64	TEST_21	7-Sep-86	19:12:19	74°18'N111°39.4'W	2/10 old, 8/10 med 1st yr, vast floes	Stopped in ice @ 19:25	
65	TEST_22	9-Sep-86	11:04:18	74°20.7'N111°40.5'W	2/10 old, 8/10 thk 1st yr, vast floes	Testing floe	
66	TEST_23	9-Sep-86	19:28:28	off Cp. Clarendon	4/10 old, 6/10 thk 1st yr, vast floes	On ice trials	
67	TEST_24	9-Sep-86	20:21:09	off Cp. Clarendon	4/10 old, 6/10 thk 1st yr, vast floes	On ice trials	
68	TEST_25	11-Sep-86	6:05:05	74°02.7'N111°15.1'W	4/10 old, 5/10 thk 1st yr, vast floes	enroute to Pr.of Wales	DECLUTCH STBD. @ 11:00
69	TEST_26	11-Sep-86	11:14:17	74°18.7'N111°10.1'W	4/10 old, 5/10 thk 1st yr, vast floes	enroute to Pr.of Wales Str.	
70	TEST_27	11-Sep-86	12:28:58	74°02.4'N111°43.1'W	4/10 old, 5/10 thk 1st yr, vast floes	enroute to Pr.of Wales Str.	
71	TEST_28	12-Sep-86	11:02:11		5/10 old, 4/10 med1st yr, vast floes		
72	TEST_29	13-Sep-86	7:53:05		7/10 old, 2/10 med1st yr, vast floes		

Table 5.2.1 Events Log (cont.)

EVENTS	LOG						
EVENT #	LABEL	DATE	TIME	LOCATION	ICE CONDITIONS	SHIP STATUS	COMMENTS/ OBSERVATIONS
73	BOL_PUSH	12-Sep-86	19:01:01		7/10 old, 3/10 med1st yr, vast floes		
74	BOL_1_2	12-Sep-86	19:41:49		7/10 old, 3/10 med1st yr, vast floes		
75	RAM_1	12-Sep-86	19:08:11		7/10 old, 3/10 med1st yr, vast floes		
76	RAM_2	12-Sep-86	19:11:12		7/10 old, 3/10 med1st yr, vast floes		
77	RAM_3	12-Sep-86	19:14:03		7/10 old, 3/10 med1st yr, vast floes		
78	RAM_4	12-Sep-86	19:16:07		7/10 old, 3/10 med1st yr, vast floes		
79	RAM_5	12-Sep-86	19:28:07		7/10 old, 3/10 med1st yr, vast floes		
80	RAM_6	12-Sep-86	19:47:34		7/10 old, 3/10 med1st yr, vast floes		
81	RAM_7	12-Sep-86	20:04:59		7/10 old, 3/10 med1st yr, vast floes		
82	RDA_STB1	13-Sep-86	11:09:53		7/10 old, 2/10 med1st yr, vast floes		
83	RDA_PORT1	13-Sep-86	11:12:30		7/10 old, 2/10 med1st yr, vast floes		
84	RDA_SBD	13-Sep-86	10:30:23		7/10 old, 2/10 med1st yr, vast floes		
85	RDA_PORT	13-Sep-86	10:34:14		7/10 old, 2/10 med1st yr, vast floes		
86	RDA_0	13-Sep-86	11:25:37		7/10 old, 2/10 med1st yr, vast floes		
87	STOP_01	3-Sep-86	17:36:02	74°32.3'N111°09.0'W	2/10 old, 8/10 thk 1st yr ice,vast floes	cargo away & mobilize	
88	STOP_02	15-Sep-86	13:44:29		open water		
89	STUCK_1	28-Aug-86	8:36:26	73°30'N114°2.8'W	10/10 old ice,vast floes	Stopped in Ice	
90	STUCK_2	28-Aug-86	8:45:19	73°30'N114°2.8'W	10/10 old ice,vast floes	Stopped in Ice	
91	OPEN_1	27-Aug-86	17:25:57	73°05.6'N116°50.3'W	4/10 thk 1st yr, 1/10 thn 1st yr ,small-med floe	vessel underway	
92	OPEN_2	27-Aug-86	18:03:41	73°05.6'N116°50.3'W	4/10 thk 1st yr, 1/10 thn 1st yr ,small-med floe	vessel underway	
93	OPEN_3	1-Sep-86	13:14:57		1/10 old ice, landfast	A/S John A MacDonald	
94	OPEN_4	1-Sep-86	16:12:32		1/10 old ice, landfast	A/S John A. Macdonald for ice trial meetings	
95	OPEN_5	2-Sep-86	8:50:47	74°40'N99°36.5'W	1/10 thin 1st yr, ladnfast ice	A/S John A. Macdonald for ice trial meetings	

5.3. Ice Conditions

A summary of the sea ice characterization during the voyage of the M.V. Kalvik is listed in Table 5.3.1. During the voyage to Resolute, N.W.T., central and southern Viscount Melville Sound contained 6 tenths old ice and 4 tenths first year ice. The heaviest ice conditions encountered were in the western Viscount Melville Sound and high loads on the propulsion system were measured.

From September 4 to 15, 1986, the south and central part of Viscount Melville Sound was covered with close pack ice, comprising mostly second and multi-year ice, while the northern area was composed mostly of first year ice. Total concentrations ranged from 8 to 9+ tenths, with a tendency for lower pressures and more leads later in the test period.

As shown in Figure 5.2 tests were conducted in four areas:

- just inside the pack ice edge off Cape Clarendon, Melville Island
- in mixed pack ice in central-northern Viscount Melville Sound
- in level ice in central Viscount Melville Sound
- in first year and old ice floes in south-west Viscount Melville Sound

Table 5.3.1 Sea Ice Characterization During Trials of M.V.Kalvik

August 26 - September 15, 1986

ICE THICKNESS		
First Year:	0.6 - 2.1 metres	Mean: 1.8 metres
Old Ice:	2.6 - 7 metres	
Number of Sites:	45	
Number of Measurements:	275	

FLEXURAL STRENGTH	
First Year Mean:	300 kPa
Old Ice Mean:	700 kPa

BOREHOLE JACK YIELD STRESS	
First Year Mean:	4.9 mPa
Old Ice Mean:	13.8 mPa

EQUIVALENT UNIAXIAL CRUSHING STRENGTH	
First Year Mean:	0.8 mPa
Old Ice Mean:	2.3 mPa

GENERAL DESCRIPTION

DATE	REGION	TOTAL ICE	FIRST YEAR	OLD ICE
08/26 - 08/27	Beaufort/Amundsen/ Prince of Wales Strait	trace	trace	0
08/27 - 08/30	Viscount Melville Sound	10	4	6
08/30	Northern Viscount Melville Sound	9+	9	1
08/30 - 09/04	Parry Channel	variable	variable	variable
09/04 - 09/11	Northern Viscount Melville Sound	9+	9	1
09/11	Central Viscount Melville Sound	9+	4	6
09/12 - 09/13	Southern Viscount Melville Sound	9+	4	6
09/14 - 09/15	Prince of Wales Strait/ Amundsen/Beaufort	trace	trace	0

Test floes were representative of all the ice types present during the test period and typical of this season in this region of the arctic. Each of the test floes is described in more detail below.

Ice Floes

September 4 - 5

Tests on September 4 and 5 were conducted in a vast, composite ice floe ten miles inside the pack ice edge off Cape Clarendon, Melville Island. The floe location on September 4 was 74°28.8'N/111°21'W.

The centre of the floe comprised hummocky old ice of average hummock thickness between 2.8 and 3.7 m and flexural strength of 270 kPa. It was not possible to measure crushing strength in this area, but it likely exceeded 600 kPa in ice not covered with refrozen melt. About 50% of the ice surface was covered with melt pools, all of which were frozen and lightly snow-covered. Cakes and small floes of old ice were also present on the west side of the floe, frozen in a first year ice matrix. Small, first year ridges were present at the floe edges and one of these was transited by the ship.

The perimeter of the floe (approximately 60% of the total area) was first year of 1.3 to 2.2 m total thickness and flexural strength of 230 kPa. The first year ice had an undulating surface due to melt from this summer, and had a uniform snow cover of about 2 cm.

Surrounding floes were of similar ice but were small to medium in size.

A helicopter reconnaissance was made on September 5 in an effort to locate thinner level ice. It included a flight to Liddon Gulf and along the south shore of Dundas Peninsula. It showed the test floe to be typical of the near shore region, which included composite floes of first year and old ice in the range of 1 to 5 miles diameter.

Floes in central Melville Sound tended to be larger, and two vast floes of uniform ice were observed at about 74°14.5'N/111°43'W. One of these was split by the northbound track of M.V. Kalvik. A thickness of 1.7 m was measured on this floe.

Test floes September 6 - 10

Trials on September 6 - 10 were in the large floe containing the ship track, identified during the reconnaissance of September 5. It was a vast composite floe with undulating old ice in the centre and level to undulating ice with old ice inclusions on the periphery. It also included an extensive area of first year ridging and smaller areas of very level ice. Trials were conducted in all types of ice present in the floe.

Mean thicknesses in the trials areas ranged from 1.2 to 2.6 m. Measured ridging in first year ice ranged from sail heights of 2 to 3.5 m and keel depths to 3.2 m. Flexural strength calculated from temperature/salinity measurements ranged from 232 to 582 kPa and crushing strengths estimated from Borehole Jack tests were in the vicinity of 1 MPa.

Snow cover ranged between about 2 cm on level ice to 15 cm on hummocky ice.

First year ridges were present at the floe edge, and a moderate degree of ridge building took place during the trials program as moving ice impinged on the south shore of Melville Island at Cape Hay. One ridge was traversed by the ship on each of September 6, 7 and 8.

The ridge traversed on September 8 was among the largest present. A plan view, cross and longitudinal profiles of this ridge are shown in Figure 3.5. It was a weakly consolidated first year ridge of maximum sail height 1.4 m and keel depth 3.7 m, with typical block thickness 1.5 m.

A reconnaissance was also made of a smaller floe (big floe category) at 74°12'N/111°04'W adjacent to the main test floe, because it appeared somewhat more uniform in surface topography. On-ice measurements showed that it was similar to the test floe and included level ice of 1.6 m thickness and undulating ice of 2.2 m thickness, with 15 cm of snow cover in the melt channels.

September 11

September 11 was spent in transit, mainly in leads through mixed first year old ice in big floe sizes (Figure 2). Resistance trials were conducted enroute in a level ice floe with thickness estimated at 1.2 to 1.5 m. No on-ice measurements were conducted.

Test floes September 12 and 13

Two sets of trials were conducted on September 12 and 13, north of the entrance to Prince of Wales Strait. Ridge ramming tests were conducted in a vast floe of multi-year ice which had broken off a giant floe of similar ice.

Level ice thickness in the vast floe was measured at 4 m, at a typical location, and the test ridge which was also typical of the floe, was 9 m. Flexural strength estimated from temperature/salinity measurements was 700+ kPa, and crushing strength estimated form borehole jack tests was 2.3 MPa. The giant floe from which this ice was derived had been resident in this area throughout the summer and the previous winter.

The source of the floe has not been determined; the regional ice climatology suggests it could have grown either locally or in the Beaufort Sea. The entire floe surface included multi-year ridges similar to the one profiled.

The second set of trials near the entrance to Prince of Wales Strait were resistance tests in level ice. This ice was extensively puddled, with about 5/10 of the surface area comprising flooded or slushy melt pools. Ice thickness in the melt pools was about .2 m and in the thicker areas about 1.3 m.

6. ANALYSIS OF FULL SCALE DATA (TASK 5)

6.1 Static Alignment

Introduction / Summary

The shaft alignment calculation for the propulsion shafting system of the M.V. Kalvik was performed using strain gauge techniques [1]. The results were used to assess the static loads on the bearings and establish a baseline load to compare with loads during ice breaking. The shaft train was instrumented at five selected locations to measure bending strains. It was idealized as a classical beam system and the free body diagram approach was used to calculate the bearing reactions from the measured bending strains. Alignment tests were done before the vessel was drydocked (August 4, 1986), and after the full scale tests (September 15, 1986). During the drydock the stern tube bearings were replaced by instrumented bearings.

Error analysis was done to estimate the expected errors introduced by the measurements due to instrumentation sensitivity, installation error, and uncertainty in physical properties and dimensions of the shafting system.

A system of influence coefficients for the bearing reactions given by Lloyd's Register of Shipping (Appendix C) was used to determine the misalignment of the shaft train.

The following results were obtained:

1) There is no significant misalignment of the M.V. Kalvik shaft line.

2) The forward flywheel bearing (Frame 55) is the highest loaded intermediate bearing at 0.125 MN (12.7 tonnes). Maximum continuous design load is 0.32 MN (32.6 tonnes).

3) Negligible bearing wear has occurred since the construction of the M.V. Kalvik.

4) The difference in the measured reactions and Lloyd's calculated reactions can be accounted for by:

   - displacement of the stern tube bearings by 0.2 - 0.3 mm
   - displacement of the intermediate bearings by 0.1 - 0.2 mm
   - displacement of the gear bearings by 0.05 - 0.1 mm

Instrumentation and Measurement Procedure

The shaft train was instrumented for bending strain at five selected locations. Figure 6.1.1 shows the gauge locations on the shaft system. Two uniaxial strain gauges, 180 degrees apart, and orientated longitudinally, were mounted at each location. Standard installation procedures were exercised during the installation to assure accurate alignment of the strain gauges in the axial direction.

To measure the bending strains, the shaft was rotated through 360 degrees. When the gauges are oriented vertically, 0 degrees is defined. The vertical bending strain was determined by taking half the difference in the 0 and 180 degree strain readings; half the difference in the 90 and 270 degree readings provided the transverse bending strain.

Bending strain measurements before and after testing are shown in Figures 6.1.2 and 6.1.3 respectively.

Methods of Analysis

Determination of Bearing Reactions

The shaft bending moment is obtained by applying the basic beam relationship:

$$M = \sigma I / c$$

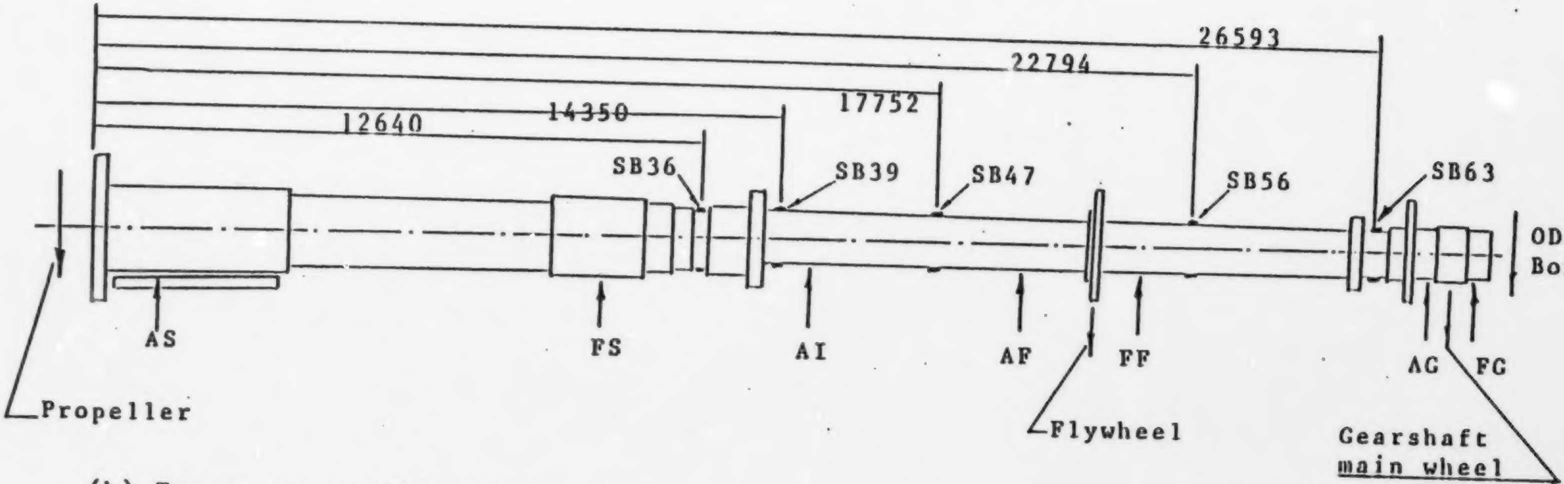
M = Bending Moment
σ = Bending Stress (calculated from measured strain)
I = Cross Section Inertia
c = Radius of Shaft

The determination of bearing reactions employed the "free body" approach [1]. The shaft train was idealized as a non-uniform beam and then divided into a series of free bodies, with measured bending stress and unknown shears at the intersections (gauge locations). The unknown shears and bearing reactions were formulated based on the static equilibrium of the free bodies, ($\Sigma F = \Sigma M = 0$).

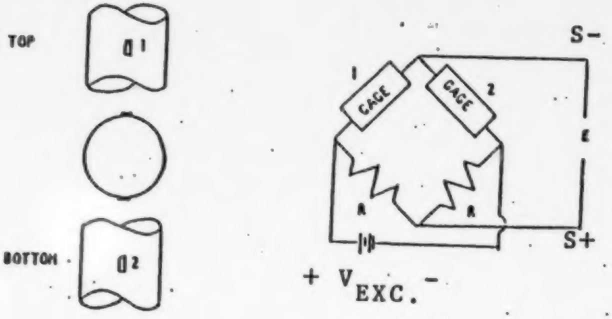
The principal data considered in analysis included the propeller weight in water, weights of the shaft, flywheel, gear wheel and oil distribution box. The effective point of support of the rotating tailshaft in the aft stern bearing was assumed at a location one third the length of the bearing from the aft edge (Lloyd's assumed operating condition - Appendix C).

The equations to determine the reactions were incorporated into software, and the program was exercised for each set of data. The data used and the equations employed are provided in Appendix C.

(a) Strain gauge locations (mm)



(b) Two-gauge configuration



AS - Aft stern bearing
FS - Fwd stern bearing
AI - Aft Intermediate
AF - Aft flywheel
FF - Fwd flywheel
AG - Aft gear
FG - Fwd gear

Figure 6.1.1 INSTRUMENTATION SYSTEM FOR SHAFT ALIGNMENT

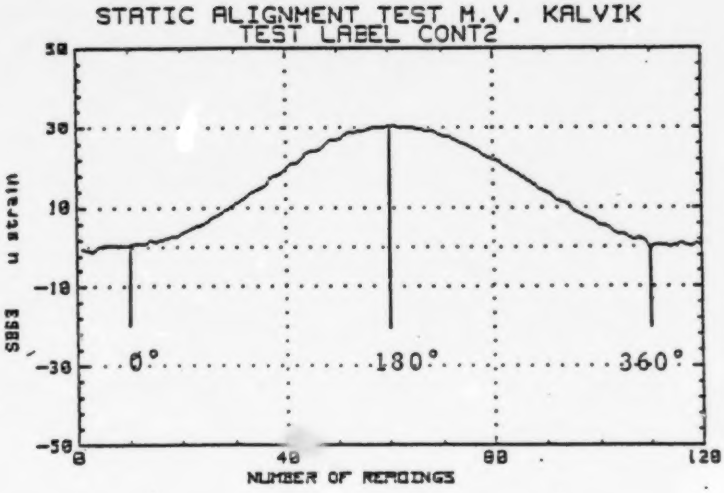


Figure 6.1.2 Shaft Bending Strain Frame 63 - August 4, 1986

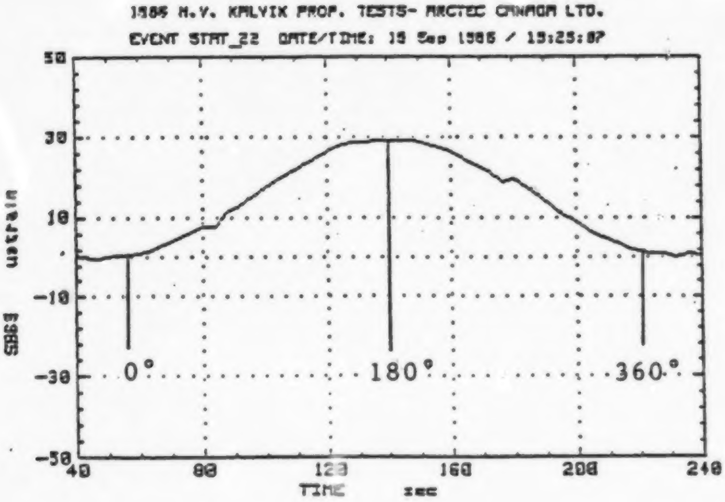


Figure 6.1.3 Shaft Bending Strain Frame 63 - September 15, 1986

Reaction Error Analysis

For the strain gauge shaft alignment method, there are a number of parameters affecting the accuracy of the bending moment measurements, and thus the determination of bearing reactions. These include:

1) Gauge Misalignment - ±1% - The misalignment error in a uniaxial stress field depends on the amount which the gauge is aligned off the axial direction.

2) Gauge factor variation - ±0.5%

3) Instrumentation Sensitivity - ±2%

4) Physical properties and dimensions - ±2% - Uncertainty in estimate of the elastic modulus.

Using the "free body" approach, Forrest and Labasky [1] established a method in evaluating the errors in the bearing reactions in terms of the errors due to the measured moments.

Determination of Misalignment

Bearing load influence coefficients for the shaft arrangement of M.V. Kalvik as provided by Lloyd's Register of Shipping (LRS) are listed in Appendix C. The coefficients relate the change in bearing loads due to a unit displacement of any one bearing.

Results of the alignment analysis by LRS were essentially for a minimum misalignment situation. The bearing loads derived from the present static alignment tests include effects of misalignment due to wear in line shafting and its bearings, hull girder deformations, and influences of support foundations. The difference in bearing loads between LRS's analysis and the present alignment tests reflects the amount of misalignment of the existing shaft arrangement.

Results

Bearing Reactions

Shaft bending strain measurements taken before drydock and after drydock were analysed to determine the bearing reactions. A summary of the bearing reactions calculated from the strain measurements, and those from Lloyd's vibration analysis and a jacking test performed in June, 1983, are listed in Table 6.1.1.

Table 6.1.1 Summary of Bearing Reactions
(Reaction Load Units in kN)

Bearing	Before Drydock August 4,1986	After Testing Sept.15,1986	Lloyd's Analysis November 1982	Jacking Test (June '83)	Difference Between Tests & Lloyd's
Aft Stern Tube	628	628	593	--	35.
Fwd Stern Tube	115	117	141	--	-25.
Aft Intermediate	111	109	79	80	32.
Aft Flywheel	66	67	87	79	-21.
Fwd Flywheel	125	124	151	143	-26.
Aft Gear	39	40	25	--	14.
Fwd Gear	69	68	95	--	-26.

Note: 10 kN ~ 1 tonne

Figures 6.1.4, 6.1.5 and 6.1.6 illustrate the vertical reactions calculated from the bending measurements and those calculated by Lloyd's.

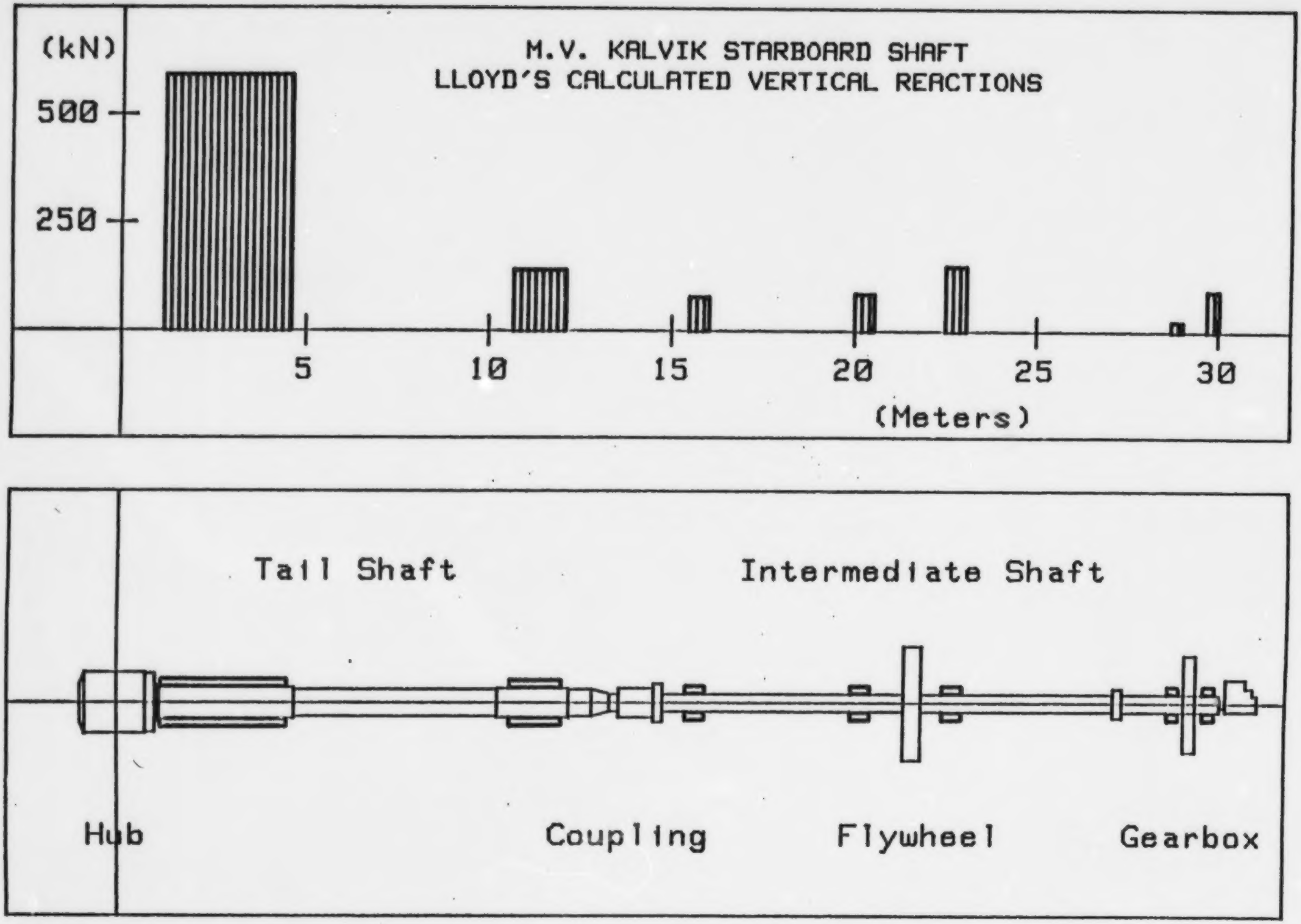


Figure 6.1.4 Lloyd's Calculated Vertical Reactions

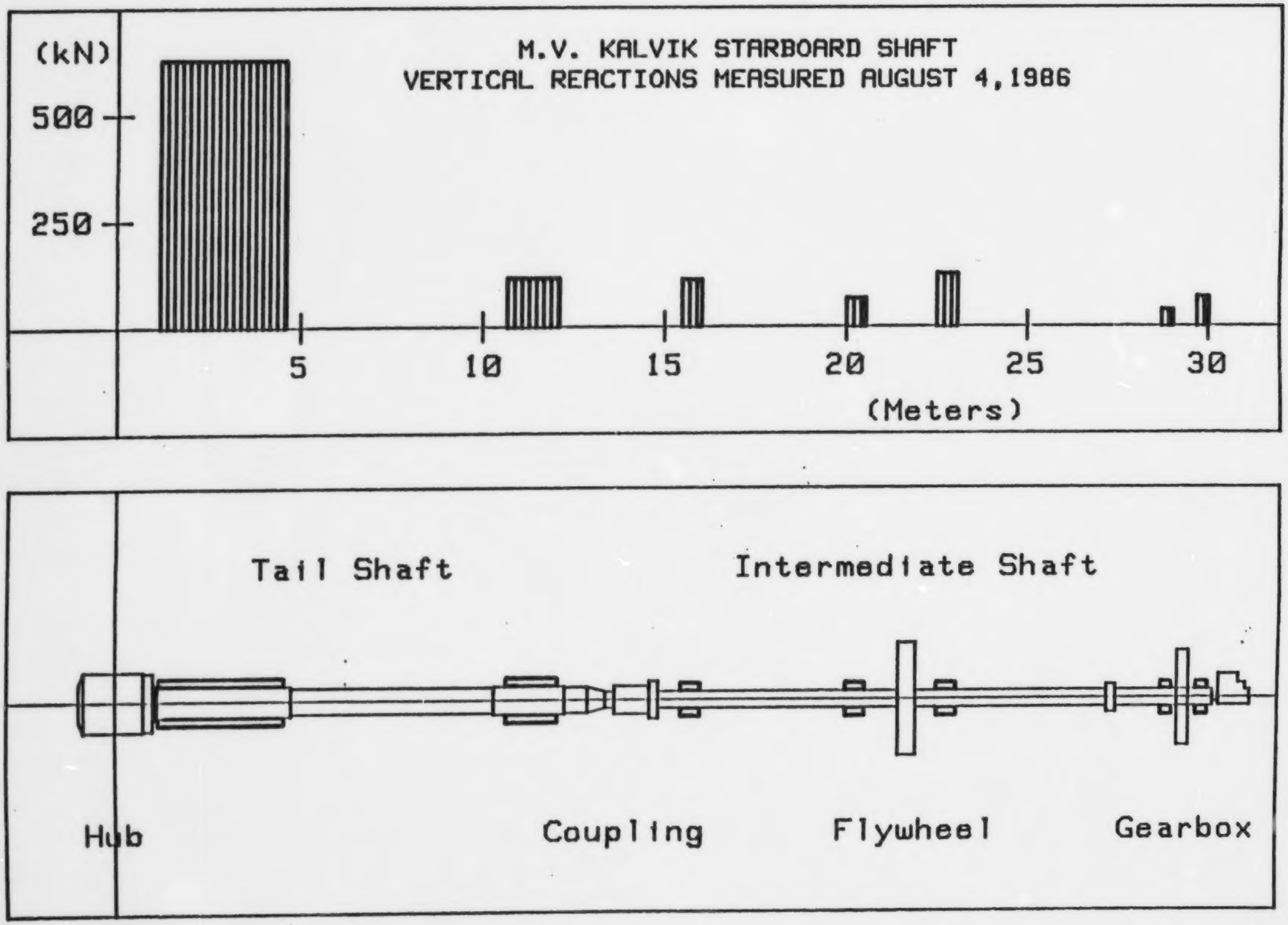


Figure 6.1.5 Vertical Reactions Measured August 4, 1986

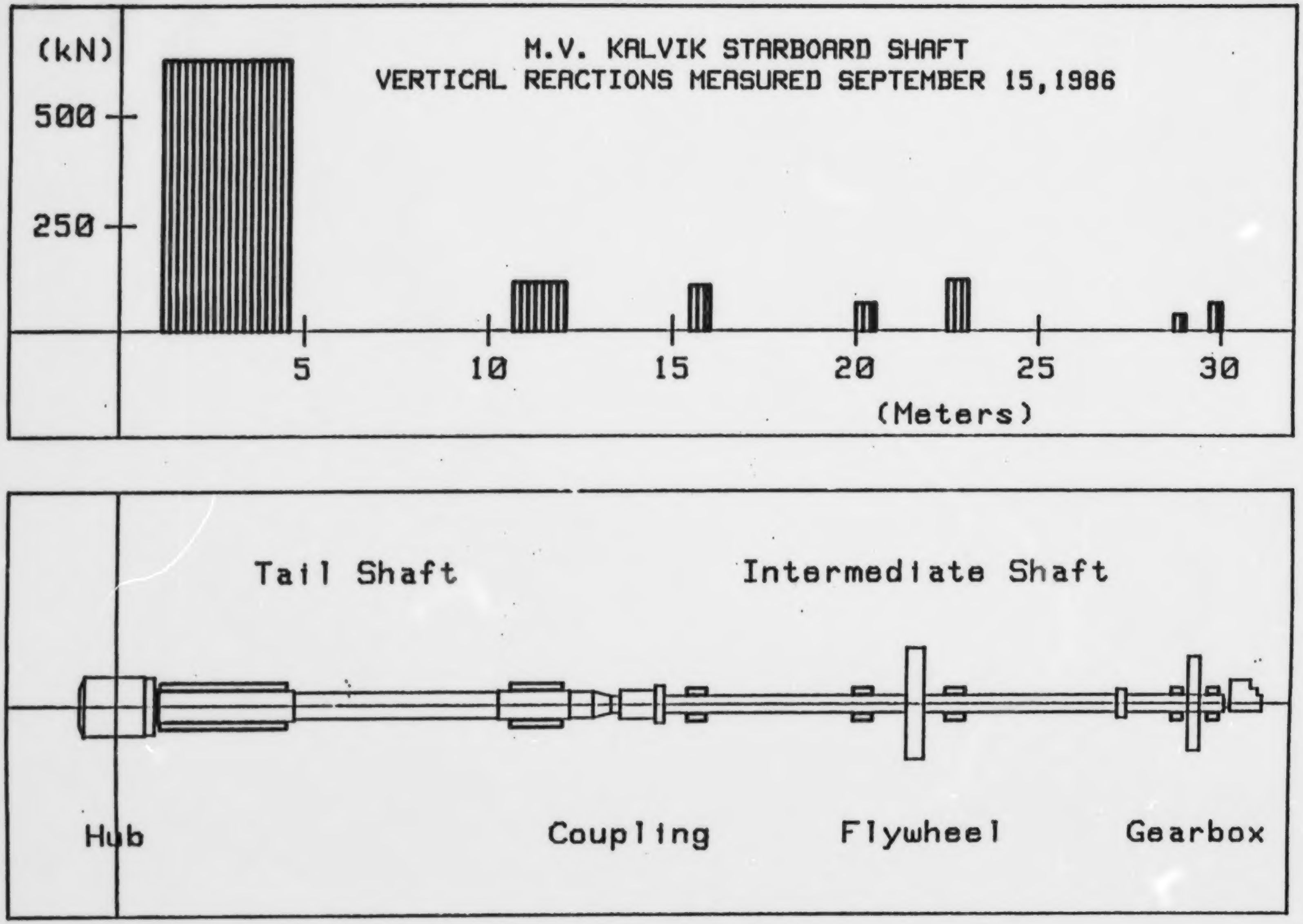


Figure 6.1.6 Vertical Reactions Measured September 15, 1986

Error Bounds

The error bound calculations performed on the reactions are given in Table 6.1.2.

Table 6.1.2 Summary of Bearing Reaction Errors

Bearing	Vertical Reaction (R) Before Dry Dock (kN)	Reaction Error (r) ±(kN)	R/r ±(%)
Aft Stern Tube	628	0.84	0.1
Fwd Stern Tube	115	3.41	3.0
Aft Intermediate	111	4.38	4.0
Aft Flywheel	66	4.59	7.0
Fwd Flywheel	125	3.48	6.5
Aft Gear	39	4.59	11.8
Fwd Gear	69	3.64	5.3

Note: 10 kN ~ 1 tonne

Details of the error bound formulation for the present shaft system of the M.V. Kalvik can be found in Appendix C.

Shaft Alignment

Alignment tests before and after drydock conditions, were analysed using the Lloyd's bearing load influence coefficients. The following conclusions were made:

- The difference in the measured reactions and Lloyd's calculated reactions can be accounted for by:
    - displacement of the stern tube bearings by 0.2 - 0.3 mm
    - displacement of the intermediate bearings by 0.1 - 0.2 mm
    - displacement of the gear bearings by 0.05 - 0.1 mm

Horizontal Bearing Reactions

The horizontal bearing reactions were also calculated. Half the bending strain difference between the 90 and 270 degree position was used to calculate the bending due to transverse misalignment. The reaction error is similar to that for the vertical reaction. Lloyd's does not calculate the horizontal reaction in their analysis.

The equation used in the calculation are the same as for the vertical reactions, but all vertical weights are set to zero.

Table 6.1.3 lists the results from the horizontal reaction calculation. The estimated maximum error is ±4 kN.

Table 6.1.3 Horizontal Bearing Reactions

Bearing	Reaction Before Drydock (kN)	Reaction After Testing (kN)
Aft Stern Tube	-1	0
Fwd Stern Tube	3	-3
Aft Intermediate	-5	1
Aft Flywheel	1	-2
Fwd Flywheel	10	13
Aft Gear	-31	-33
Fwd Gear	23	24

Note: Positive sign is towards port (10 kN ~ 1 tonne)

These results are illustrated in Figure 6.1.7 and 6.1.8.

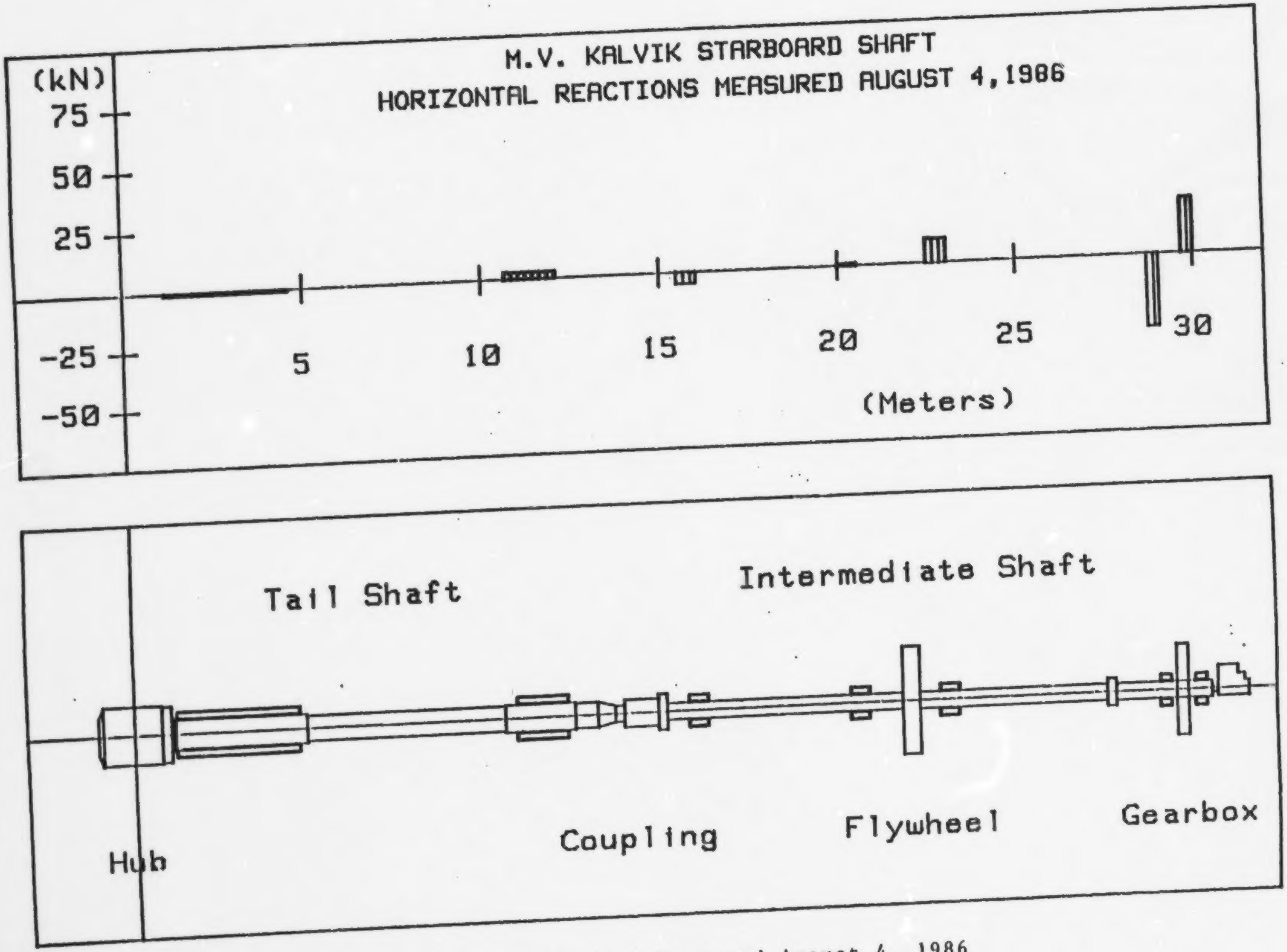


Figure 6.1.7 Horizontal Reactions Measured August 4, 1986

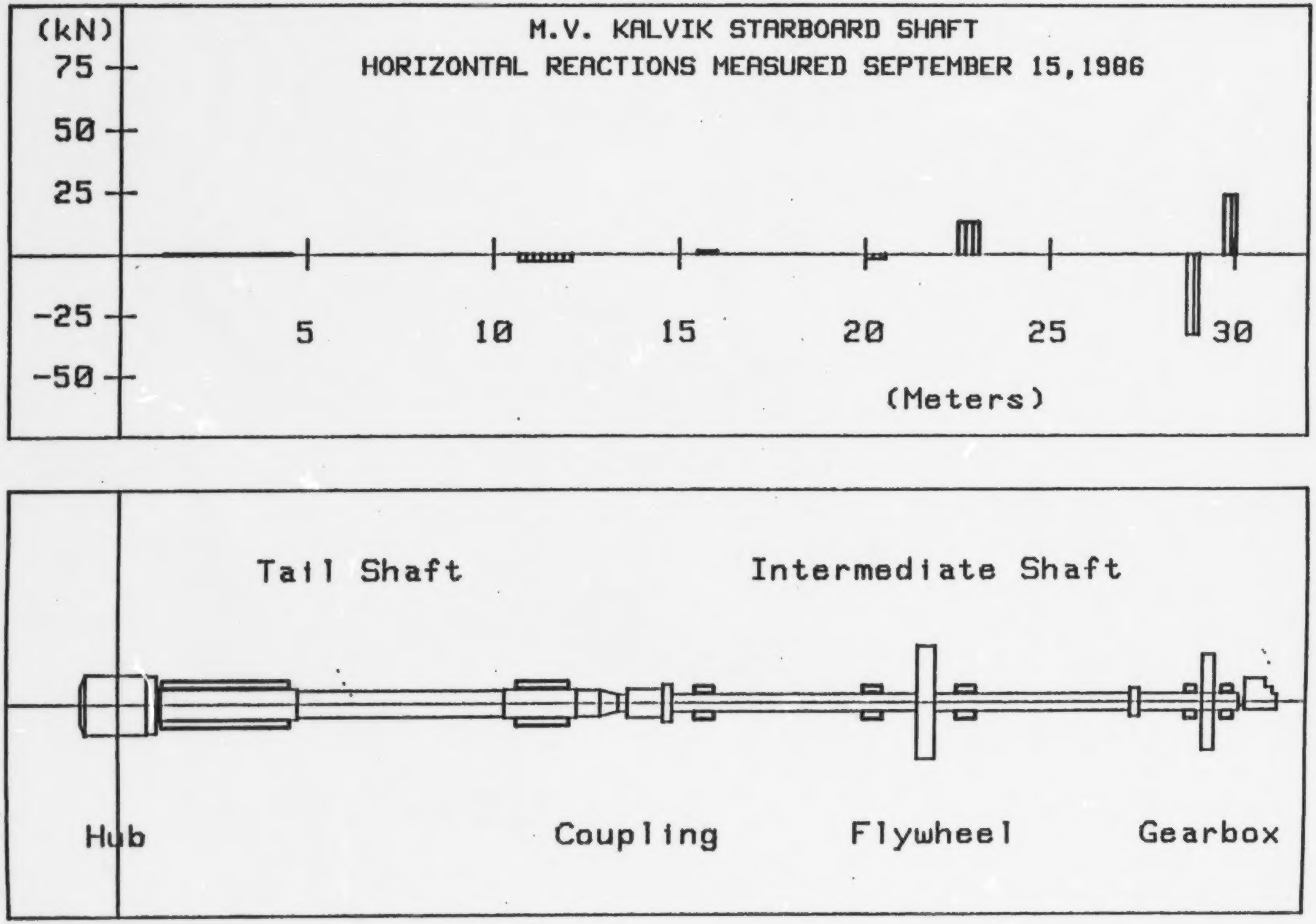


Figure 6.1.8 Horizontal Reactions Measured September 15, 1986

Conclusions

The following results were obtained:

1) There is no significant misalignment of the M.V. Kalvik shaft line.

2) The forward intermediate bearing (Frame 55) is the highest loaded intermediate bearing (0.125 MN / 125 tonnes). Maximum continuous design load is 0.32 MN / 320 tonnes.

3) Negligible bearing wear has occurred since the construction of the M.V. Kalvik.

4) The difference in the measured reactions and Lloyd's calculated reactions can be accounted for by:

   - displacement of the stern tube bearings by 0.2 - 0.3 mm
   - displacement of the intermediate bearings by 0.1 - 0.2 mm
   - displacement of the gear bearings by 0.05 - 0.1 mm

5) The calculated reactions are in reasonable agreement with Lloyd's analysis.

6) Maximum error in the calculated vertical reaction is at the aft gear bearing (0.46 tonnes - 11.8%).

7) Maximum error in the calculated vertical reaction for stern tube bearings is 3%.

8) The procedure used for calculation of shaft alignment is:

   - Simple
   - Easy to use
   - Gives reasonable results.

6.2 Statistical Analysis

To determine the expected maximum loads on a propulsion system it is essential for full scale data to be collected during the most extreme icebreaking conditions. The measurement of the response of a propulsion system to these extreme ice loads, and the condition upon which they were induced, is essential for the designer and operator to prevent damage from occurring. The M.V. Kalvik has unducted screw propellers (each with approximately 11,600 HP), and therefore very large pieces of ice can impact the propeller, which induces loads as high as one can expect on any icebreaker operating in the Canadian Arctic. The loads experienced on the M.V. Kalvik's propulsion system during the full scale tests were extreme, and in fact, the ice conditions encountered during these tests were some of the most severe the vessel has ever operated in.

The ice impacted the propeller so frequently that an unlimited amount of data could have been collected. Due to a limitation of data storage capability and the desire to collect only significant ice-propeller interactions, the data collected was biased to record only the most extreme loads on the propulsion system. Twenty-nine ice-propeller interaction events were recorded during the performance tests with the John A. Macdonald, and forty-three events were recorded during the transit from Tuktoyaktuk to Resolute Bay.

Each event recorded contained a six second window of data which included as much as 40 peak loads. To determine the extreme events to analyse and the distribution of the data collected, the maximum, minimum and mean value of all signals during each six second event was calculated and stored. Figure 6.2.1 shows a histogram of the maximum ice induced shaft thrust (increase of shaft thrust due to ice-propeller interaction) collected during the full scale tests. This thrust is proportional to the ice forces on the blades, they exceed 1 MN (100 tonnes) regularly and have values as high as 2 MN (200 tonnes). The bollard thrust is approximately 1 MN (100 tonnes) and the force to yield a propeller blade is calculated to be 2 to 3 MN (200-300 tonnes) [see Section 6.12].

Figure 6.2.2 illustrates the distribution of the maximum recorded bearing pressure above the open water pressure (0.28 - 0.70 MPa/ 40 -100 psi) on a histogram plot. The bearing pressure regularly exceeded 1.0 MPa or 1.4 times the open water pressure. There were three events where the maximum pressure exceed the open water pressure by 7 - 8 MPa (1000 -1200 psi) or by a factor of 10.

The maximum shaft thrust and shaft torque event (Test 09) and the maximum shaft movement event (Test 28) were chosen out of the data set to analyse in detail in the following sections of this report.

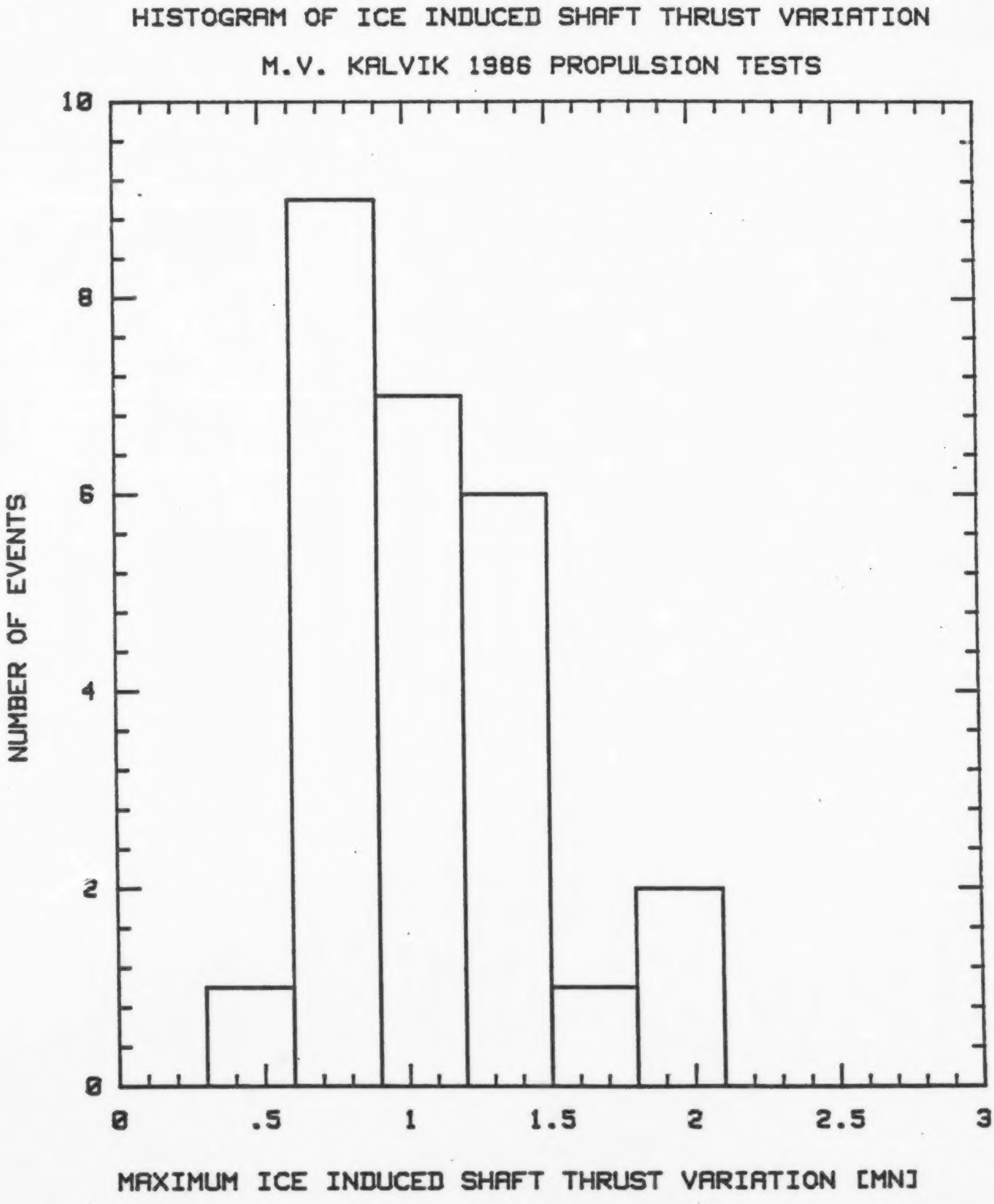


Figure 6.2.1 Shaft Thrust Histogram

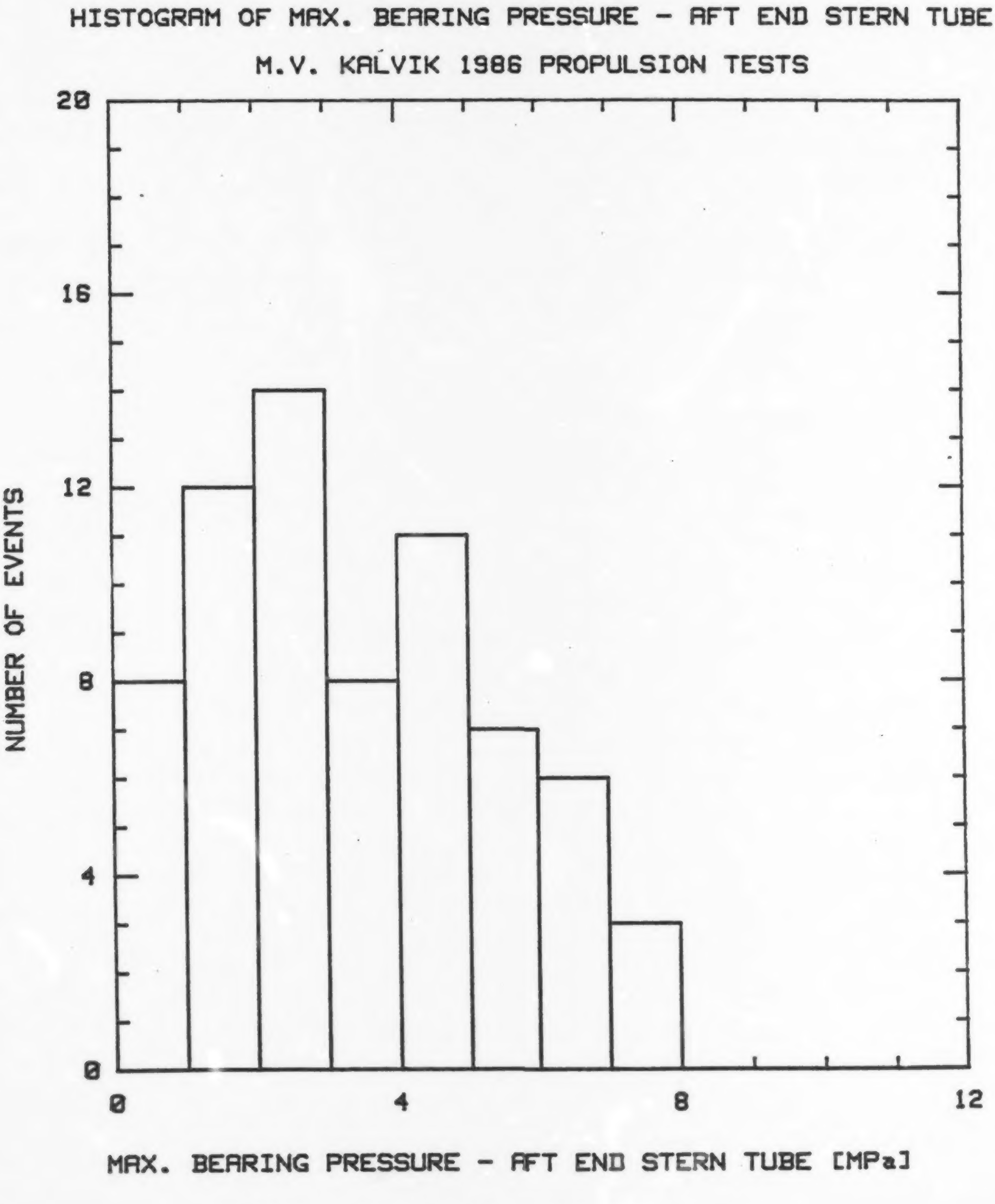


Figure 6.2.2 Aft Stern Tube Bearing Pressure Histogram

6.3 Steering Gear Loads

Introduction / Summary

This section details the data analysis of the rudder stock torque data. The instrumentation included sensors to measure strains due to torque in the rudder stock. Other relevant data including the rudder angle, pitch, shaft torque and thrust, and doppler speed were also reduced to provide an overall view of the rudder stock response.

General statistical analysis was done for all trial events, and detailed analysis of the time series plots was performed for selected extreme events. Open water events for varying rudder angles were also analysed and compared with the icebreaking cases.

The rudder is located on the center line of the vessel between the two propellers as illustrated in Figure 6.3.1 and Figure 6.3.2. The particulars are as follows:

Angular Travel	+/- 35. degrees
Rudder Stock Diameter	500. mm
Torque for Release of Hydraulic Dump Valve	1.2 MNm for 0.1 Second
Design Limit	3.0 MNm

The following results were obtained from the analysis of the data:

1. Maximum rudder stock torque measured was 1.201 MNm which is 4.6 times the maximum open water torque with a rise time of 0.2 seconds. The vessel was going astern and the rudder angle was 4.5 degrees to starboard.

2. Rudder stock torques of 0.50 to 0.90 MNm with a rise time of 0.1 second can be caused by ice being wedged between the propeller and the rudder when the vessel is moving ahead and turning in ice.

3. The maximum open water rudder stock torque measured was 0.26 MNm.

Instrumentation and Measurement Procedure

A standard full bridge strain gauge configuration was mounted on the rudder stock. The detailed calculations of the calibration factor and the torque required to release the hydraulic dump valve in the steering gear are contained in Appendix D.

The rudder stock torque signal was recorded at a rate of 500 readings per second (as were all other signals) for 6.25 seconds for each event.

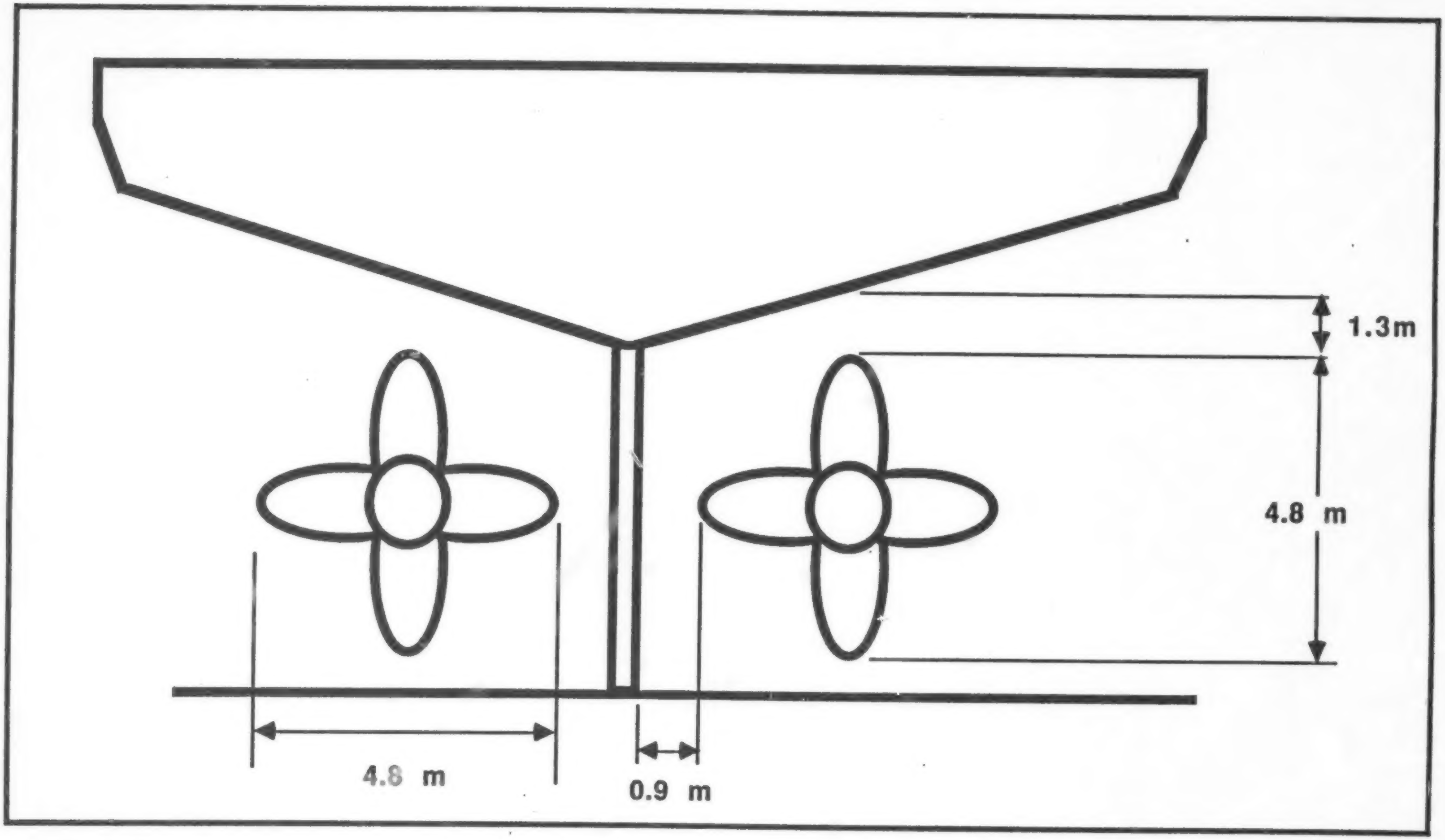
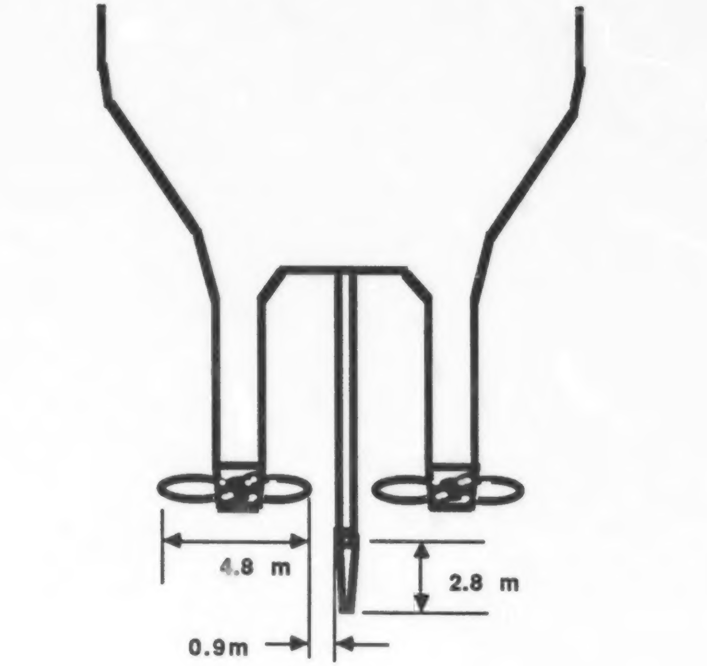
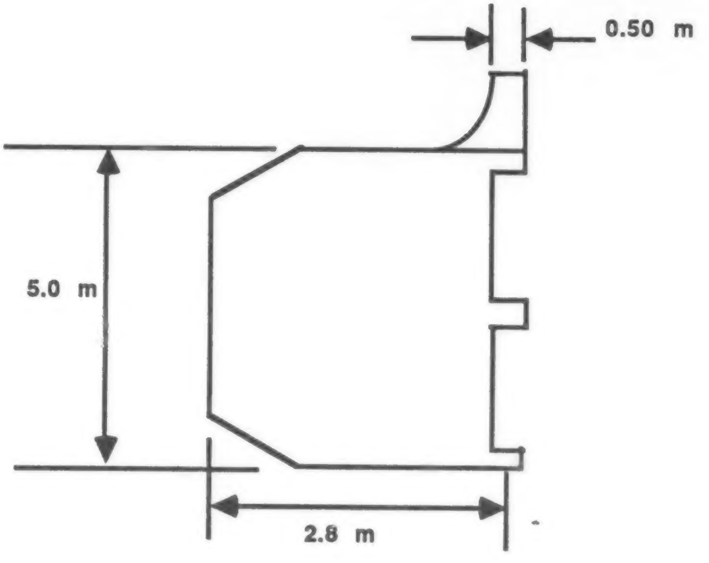


Figure 6.3.1 Transverse Section at Centerline of Hub Looking Aft



Plan View



Elevation View

Figure 6.3.2 Rudder Configuration

Data Base and Analysis Procedure

The data base for the statistical analysis includes all icebreaking events, except 24 cases between August 27 and August 28 when no rudder torque data was recorded. A total of 55 valid events were identified.

The statistical analysis included calculations of the mean, maximum and minimum values of rudder stock torque for the data base. A histogram of peak maximum and minimum rudder torque was obtained.

Based on the statistical analysis, eight extreme rudder torque events were selected and analysed:

- Continuous Icebreaking Ahead - 4 Events
- Turning to Starboard - Icebreaking Ahead - 2 Events
- Backing in Ice - 2 Events

In addition to the extreme events, detailed analysis of time series data was also performed for three selected open water events:

- Straight line course with approximately zero rudder angle
- Rudder hard over to port
- Rudder hard over to starboard

Time series data analysed included rudder stock torque, rudder angle, propeller pitch, shaft torque, shaft thrust and ship speed. This data provided information concerning the magnitudes and frequency of the loading on the rudder, the ship operation causing these loads, and the type of rudder-ice interaction.

Table 6.3.1 summarizes for each selected event the event label, the date and time, the activity category and the associated ice conditions.

Table 6.3.1 Selected Events for Detailed Analysis

Event Label	Date	Time	Operation Category	Ice Conditions
O_Ice_37	30 Aug 86	04:31:06	Continuous icebreaking ahead	10/10 old ice, vast floes
O_Ice_42	03 Sept 86	16:17:24	Continuous icebreaking ahead	2/10 old, 8/10 thick,1st yr ice, vast floes
TEST_09	05 Sept 86	13:43:22	Turning ahead - icebreaking	2/10 old, 8/10 med. 1st yr ice, vast floes
TEST_24	09 Sept 86	20:21:09	Turning ahead - icebreaking yr ice, vast floes	4/10 old, 6/10 thick, 1st
O_Ice_33	29 Aug 86	18:54:45	Continuous icebreaking ahead	10/10 old ice, vast floes
O_Ice_34	29 Aug 86	19:28:20	Continuous icebreaking ahead	10/10 old ice, vast floes
TEST_11	05 Sept 86	17:18:04	Astern - icebreaking	2/10 old, 8/10 med. 1st yr ice, vast floes
TEST_15	06 Sept 86	13:33:18	Astern - icebreaking	10/10 grey, vast floes
RDA_0	13 Sept 86	11:25:37	Open water maneuvering	Open Water
RDA_SBD	13 Sept 86	10:30:23	Turning ahead with rudder hard-over to starboard	Open Water
RD_PORT 1	13 Sept 86	11:12:30	Turning ahead with rudder hard-over to port	Open Water

Results

Result Summary

Table 6.3.2 summarizes the results of the detailed analysis for the selected extreme and open water events. Comments relevant to the ice/rudder interaction were given to explain the cause for the rudder stock torque deviation.

Table 6.3.2 Summary of Rudder Stock Torque Events

Event Label	Category	Maximum Rudder Torque (MNm)	Rudder Angle (deg)	Pitch (deg)	Shaft Torque (kNm)	Shaft Thrust (MN)	Ship Speed (m/S)	Mean Ice Thickness (m)	Comments
RDA.0	Maneuvering in open water	-0.034	0	20	320	0.28	0.5	Open Water	Hydrodynamic loading Blade frequency was observed in rudder torque response
RDA.SBD	Turning stbd in open water	0.150	37	15	290	0.35	0.5	Open Water	Hydrodynamic loading Blade frequency was observed in rudder torque response
RD.PORT1	Turning port in open water	-0.260	-28	25	500	0.40		Open Water	Hydrodynamic loading Blade frequency was observed in rudder torque response
O_ICE_37	Cont. IB Ahead	0.863	-8	21.5	—	—	—		Ice floe between stbd propeller and rudder
O_ICE_42	Cont. IB Ahead	1.087	-5.5	20.6	780	0.8	3.2		Ice impacting rudder - stbd
TEST_09	Turning ahead	0.562	36	19	800	0.9	2	1.3	Ice floe between stbd propeller and rudder
TEST_24	Turning ahead	0.336	20	20	800	0.7	3.4	1.8	Ice impacting rudder - stbd
O_ICE_33	Cont. IB ahead	-0.817	-9	26	—	—	—		Ice floe between port propeller and rudder
O_ICE_34	Cont. IB ahead	-0.857	-9	25	—	—	—		Ice floe between port propeller and rudder
TEST_11	Astern	-1.049	5.2	-16	360	-0.35	1.8		Rudder impacting ice when ship going astern
TEST_15	Astern	-1.201	4.5	-11	600	-0.2	1.6	1.8	Rudder impacting ice when ship going astern

Open Water Events

Figures 6.3.3a to 6.3.3c depict the time history responses of the rudder stock torque for the three selected open water events. Table 6.3.3 lists the important parameters derived from these figures.

Table 6.3.3 Summary of Open Water Events

Event Label	Ship Activity	Mean Rudder Torque (MNm)	Maximum Peak-to-Peak Variation (MNm)	Rudder Angle (deg.)
RDA_0	Straight line Course	-0.034	0.020	0.
RDA_SBD	Turning starboard	0.150	0.060	37.
RD_PORT 1	Turning port	-0.260	0.100	-28.

For the open water tests, the loads on the rudder are due to the hydrodynamic action of the propeller slipstream. The differences in the peak amplitude variation in rudder torque between the zero and the two rudder hard-over turning cases result from changes in the hydrodynamic forces.

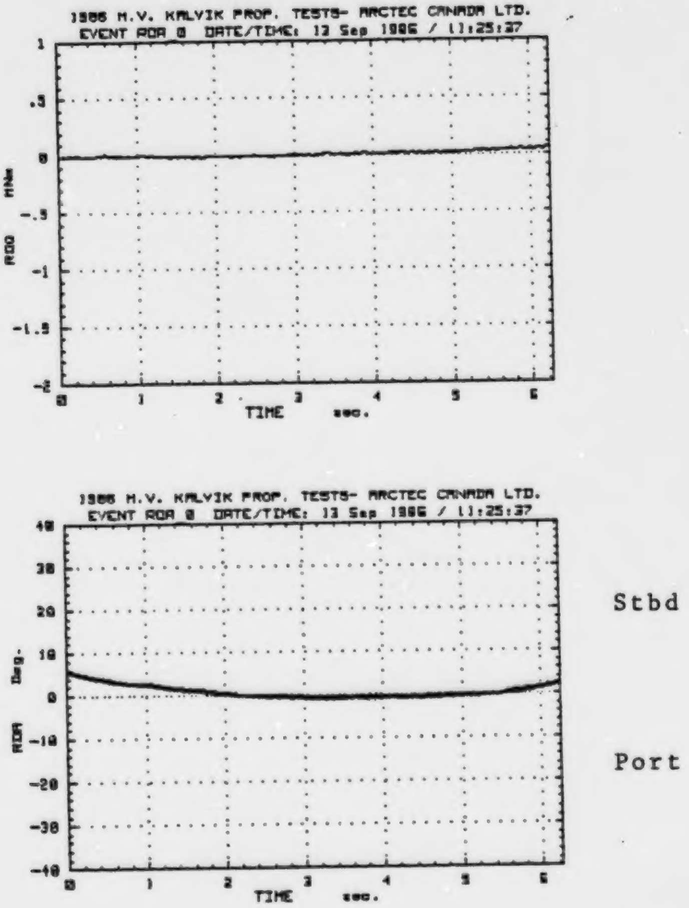
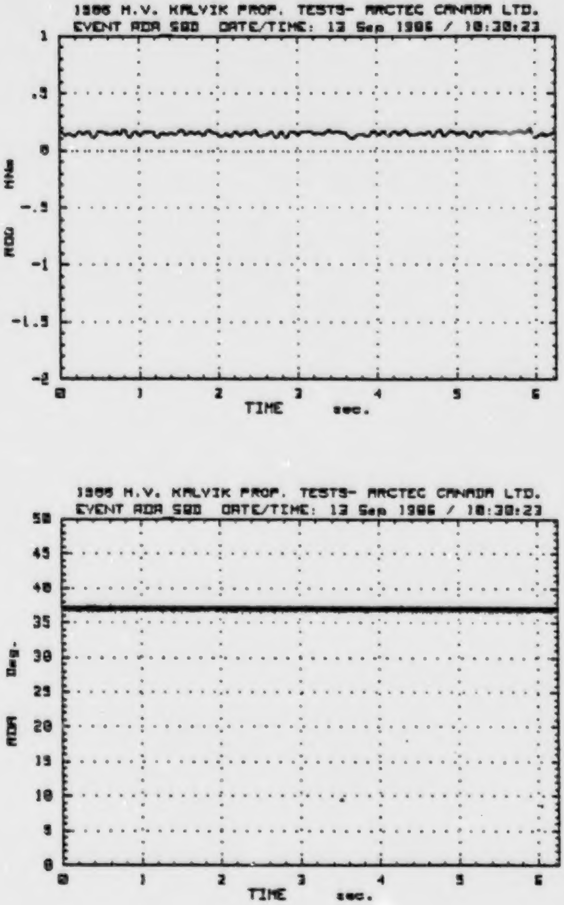


Figure 6.3.3a Rudder Stock Torque and Rudder Angle - Open Water



Stbd

Figure 6.3.3b Rudder Stock Torque and Rudder Angle - Open Water - To Stbd

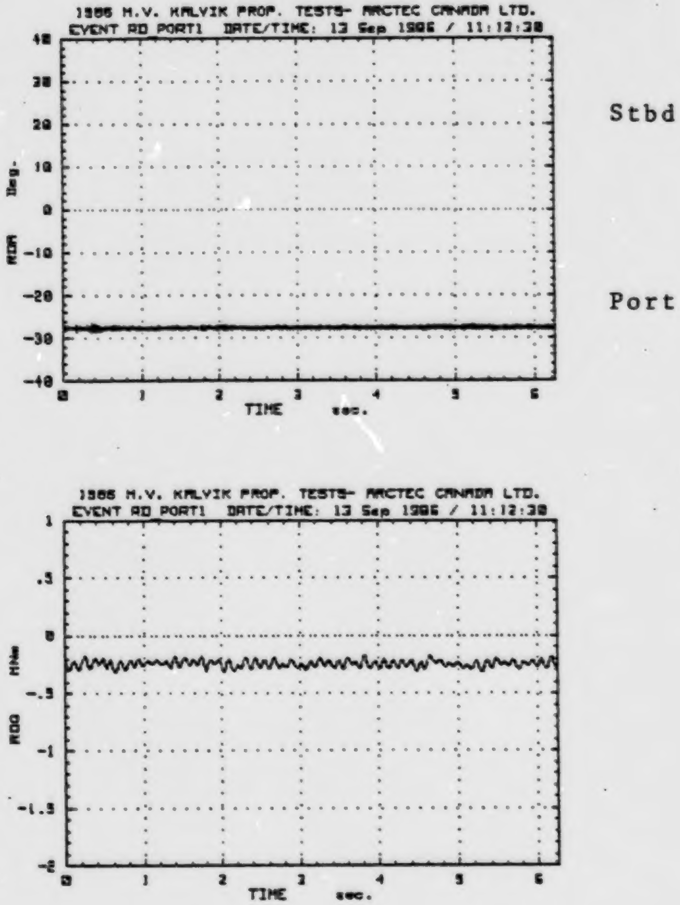
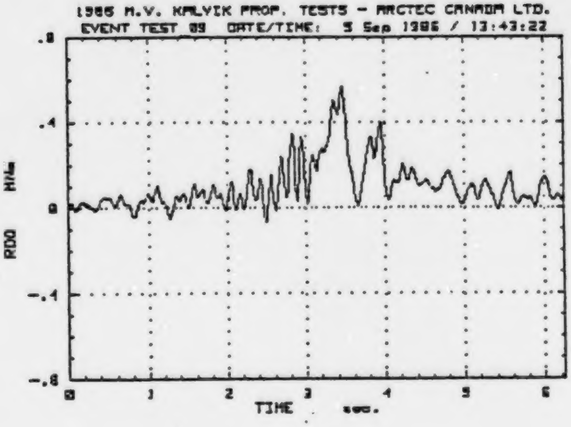


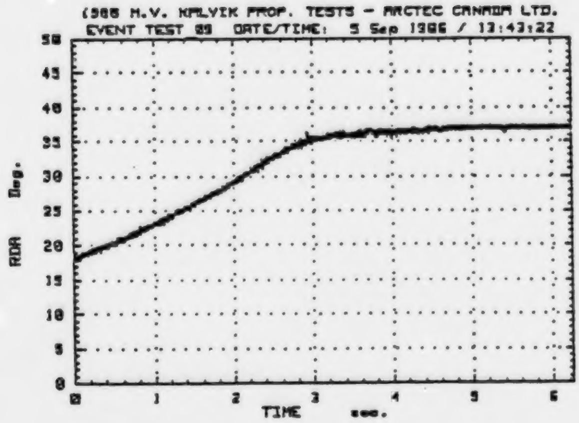
Figure 6.3.3c Rudder Stock Torque and Rudder Angle - Open Water - To Port

Maximum Shaft Thrust - Ice Propeller Impact (Event Test_09)

Time history plots of the rudder stock torque and the corresponding rudder angle are illustrated in Figure 6.3.4. The rudder was directed to the starboard from 18 degrees to 35 degrees (hard-over). Ice became wedged in between the rudder and the starboard propeller. The propeller milled the ice for approximately 1.8 seconds and then open water conditions resumed. The ice milling occurred between 2 and 3.8 seconds in the time history. The rudder ice impacts lasted from 2 to 5 seconds with the maximum torque occurring at 2.4 seconds. Figure 6.3.5 and Figure 6.3.6 show the rudder stock torque and shaft thrust for the period of 2.4 to 3.2 seconds.

When the rudder reached 35° an ice floe impacted on the starboard side of the rudder. The frequency of the rudder stock torque variation was approximately the blade rate (8.7 Hz), indicating that the ice floe was being pushed against the rudder by the propeller, as illustrated in Figure 6.3.7. The maximum ice torque obtained was 0.562 MNm (56.2 tonne meters) to the port direction. The rise time of the impact varied from 0.1 to 0.5 seconds.





Stbd

Figure 6.3.4 Rudder Stock Torque and Rudder Angle
- Ice Breaking Ahead
- Rudder Angle - To Stbd

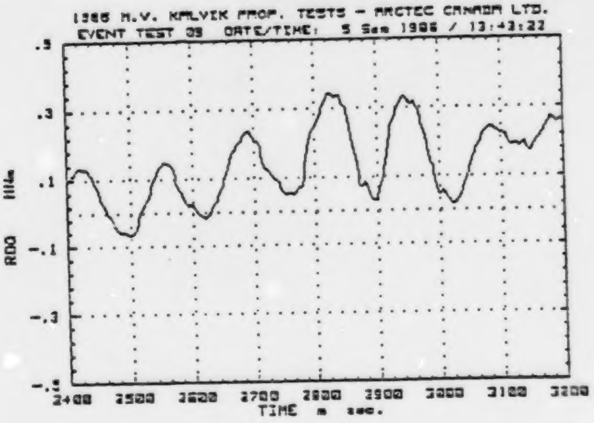


Figure 6.3.5 Rudder Stock Torque
- Ice/Rudder/Propeller Interaction

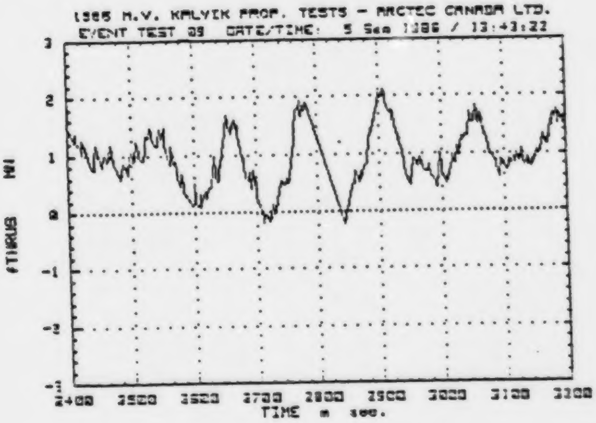


Figure 6.3.6 Shaft Thrust
- Ice/Rudder/Propeller Interaction

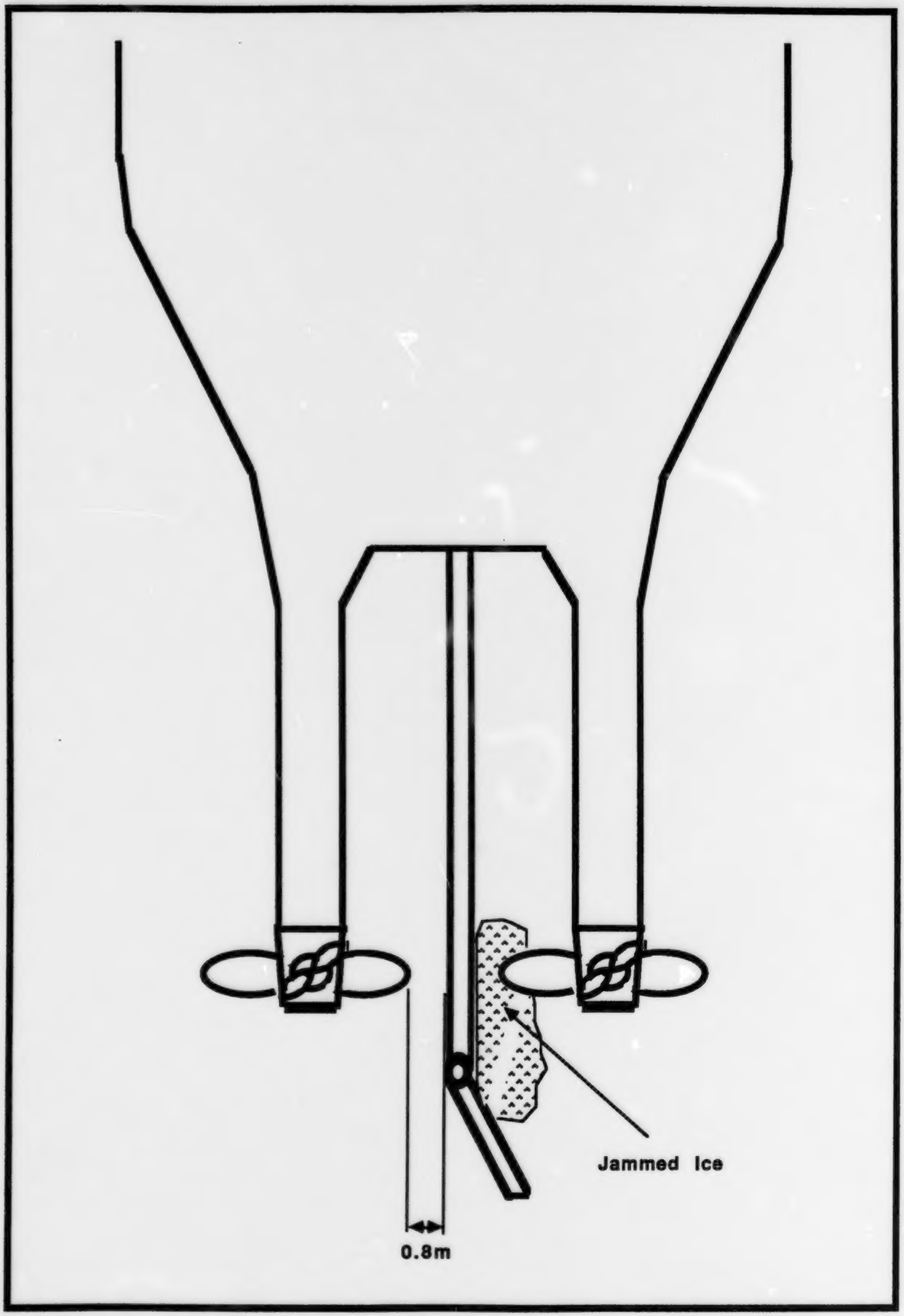


Figure 6.3.7 Rudder Ice Interaction Plan View

Astern Mode (Maximum Measured Rudder Stock Torque Test_19)

Time history plots of the rudder stock torque and the corresponding rudder angle for an event involving icebreaking astern is shown in Figure 6.3.8.

The vessel was backing up in ice with the rudder maintaining at a constant angle of 4.5° to the starboard. Hydrodynamic loading was present for the first 1.6 seconds. During the period between 1.6 and 4.2 seconds, the rudder experienced a number of ice impacts on the rudder port plane causing a series of negative rudder stock torque variations (pushing rudder to starboard). The typical rise time of these torque pulses was 0.2 seconds. The largest impact occurred at about 4 seconds, with a maximum ice torque of 1.20 MNm (120 tonne meters) to the starboard direction. After 4.2 seconds no significant ice impact was observed indicating the clearance of ice from the rudder.

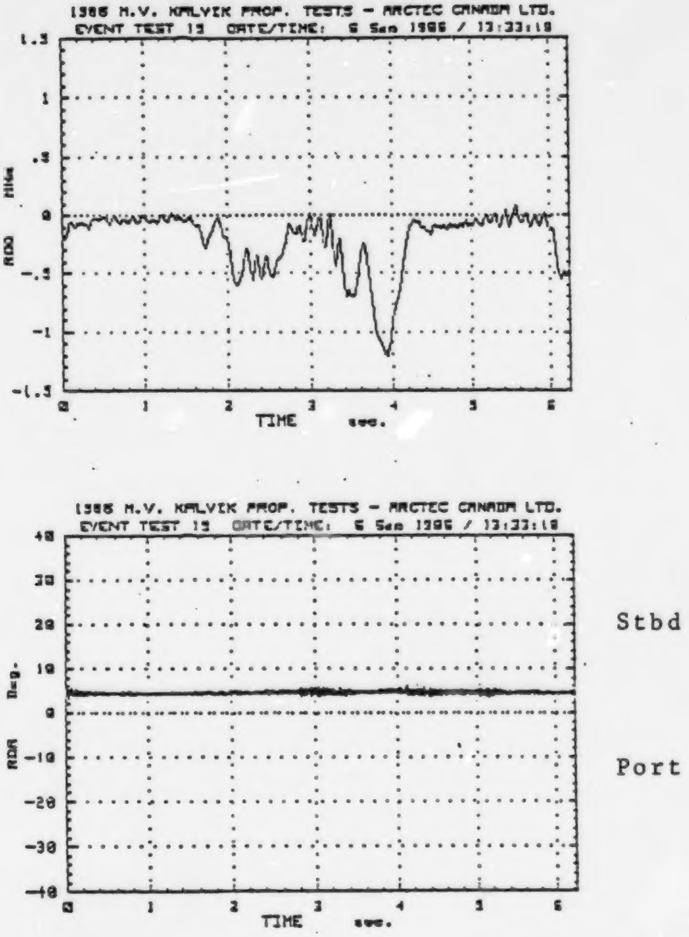


Figure 6.3.8 Rudder Stock Torque and Rudder Angle - Astern Mode

6.4 Stern Tube Bearing Loads

Introduction / Summary

In previous work, the calculation of stern tube bearing reactions have been based on secondary measurements such as the motions of the shaft. One of the main objectives of this project was the direct measurement of the magnitude and distribution of the reactions of the the stern tube bearings during ice propeller interactions.

The stern tube bearings in the M.V. Kalvik consist of salt water lubricated rubber stave bearing manufactured by The Johnson Rubber Company. The aftermost section is 3.4 m long with a 0.840 m inside diameter and the forward section is 1.5 m long with a 0.802 m inside diameter. Figure 6.4.1 shows the general arrangement of the bearings. Photographs of the bearings can be found in Appendix E.

A summary of significant results is given in Table 6.4.1.

Table 6.4.1

Summary Table of Significant Stern Tube Bearing Results

	FORWARD BEARING	AFT BEARING
Max. Local Pressure Measured	5.0 MPa (725 psi)	7.0 MPa (1000 psi)
Max. Estimated Local Pressure	5.0 Mpa (725 psi)	8.0 MPa (1160 psi)
Max. Compression of bearing	2.5 mm (0.1 in.)	4.0 mm (0.17 in.)
Max. Vertical Reaction	0.6 - 1.0 MN (61-102 tonnes)	1.5 - 2.0 MN (153 - 204 tonnes)
Max. Transverse Reaction	0.6 - 1.0 MN (61-102 tonnes)	1.1 - 1.6 MN (112-163 tonnes)
Max. Magnitude of Reaction	0.7 - 1.1 MN (71-112 tonnes)	1.6 - 2.2 MN (163-224 tonnes)
Range of Resultant Angle	0 +/- 60 degrees	0 +/- 90 degrees

The following conclusions can be made:

- The most severe reactions of the bearing were recorded when the block of ice was inboard of and below the propeller hub.
- During maximum loading of the aft bearing approximately 60% of the aft stern tube bearing length is loaded.
- The longitudinal aft stern tube bearing reaction distribution is maximum at the aft end of the bearing and minimum at approximately 2 m from the aft end and then rises again at the forward end of aft bearing to 50 - 75% of the maximum measured.

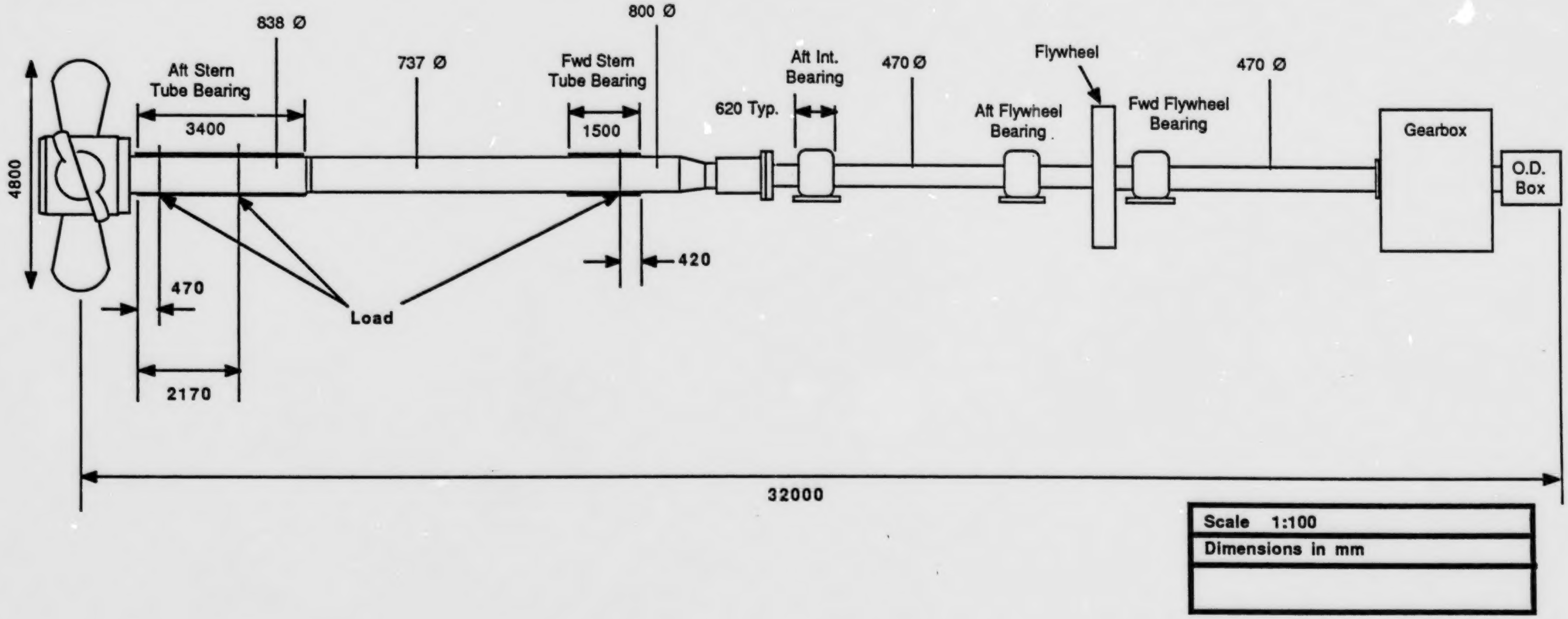


Figure 6.4.1 Starboard Shafting - Stern Tube Bearing Measurements

Instrumentation

The rubber stave bearings were instrumented to measure local pressure at 33 locations by placing strain gauges in the back of the staves as outlined in Section 4.2. The strain gauges were arranged to determine the load distribution circumferentially and longitudinally.

The gauges were arranged in two rings, 0.47 m and 2.17 m, from the aft end in the aftermost bearing and 0.43 m from the forward end of the forward bearing to determine the circumferential distribution. Additional gauges were also placed at the 5 o'clock position along the bearing providing longitudinal distribution information. Gauges were not placed in the 11, 12, or 1 o'clock staves due to installation restrictions. The strain gauge layout is shown in Figure 4.2.2 and a detailed description of the bearing, instrumentation, installation and calibration can be found in Section 4.2.

Analysis Method

The following steps outline the procedure and assumptions made in calculating the total reaction of the bearing from strains measured at the 33 locations.

1) BASE LINE CALCULATION - It is assumed that at some point in time during the "captured time window", each individual gauge in the bearings is completely unloaded which produces a minimum compressive strain at that gauge. By using this value as a baseline, change from the baseline give the absolute change in compression at that location.

2) LOCAL PRESSURE - The strain gauges placed in the bearing stave measure the local compressive strain occurring instantaneously at that bearing location. The strain reading is converted to local pressure on the surface of the stave using the calibration factor calculated from work in the lab and field (see Section 4.2).

3) LOCAL REACTION - The local pressure on a single stave is converted to a reaction/per unit length at that gauge location by multiplying the pressure measured (Step 2) by the circumferential arc length of the individual stave that is capable of carrying a hydrodynamic wedge (Figure 6.4.3). For staves with one gauge the arc length assumed is 0.16 m and for staves with two gauges side by side a arc length of 0.8 m is assumed. This reaction acts radially through the stave. By knowing the measured reaction magnitude and staves angular location, the components of the reaction in the vertical and horizontal direction can be calculated (Figure 6.4.4).

4) REACTION AT TRANSVERSE LOCATIONS - At three longitudinal locations, two in the stern and one in the forward bearing, there are sufficient gauges circumferentially to estimate the total reaction/per unit length on the bearing at that location. The total reaction/unit length is equal to the sum of the reactions of all staves as calculated in Step 2.

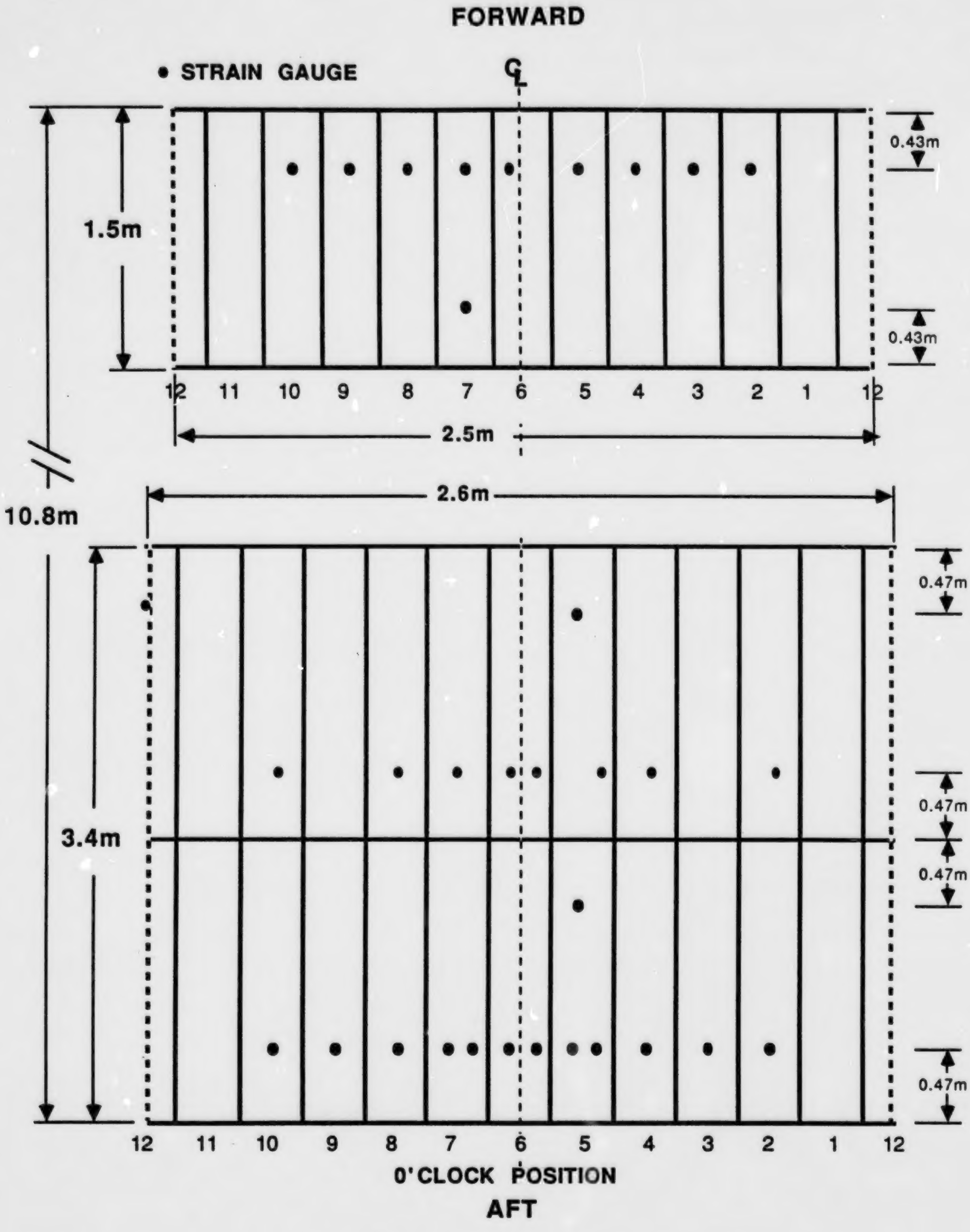


Figure 6.4.2 Projection of Stern Tube Bearings Showing Strain Gauge Location

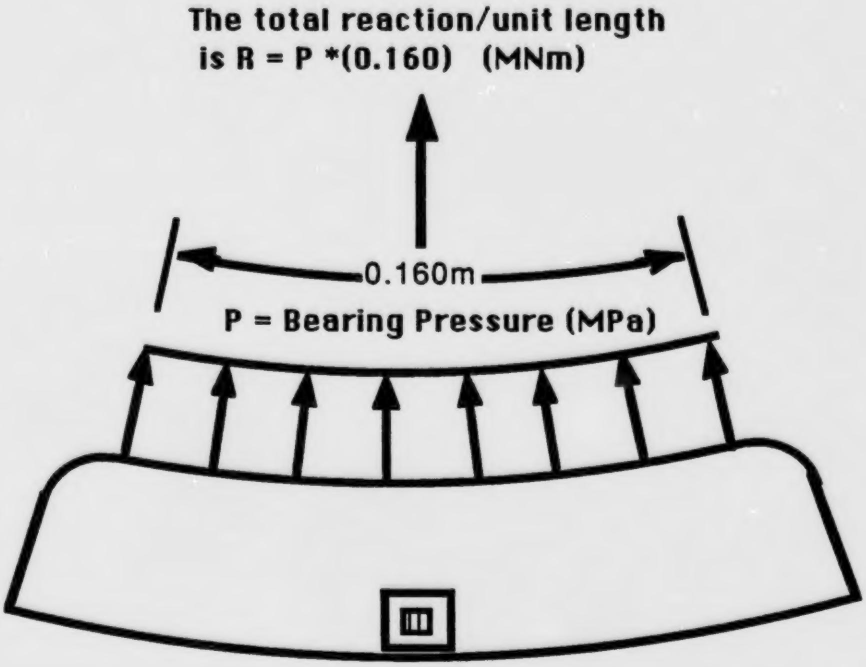
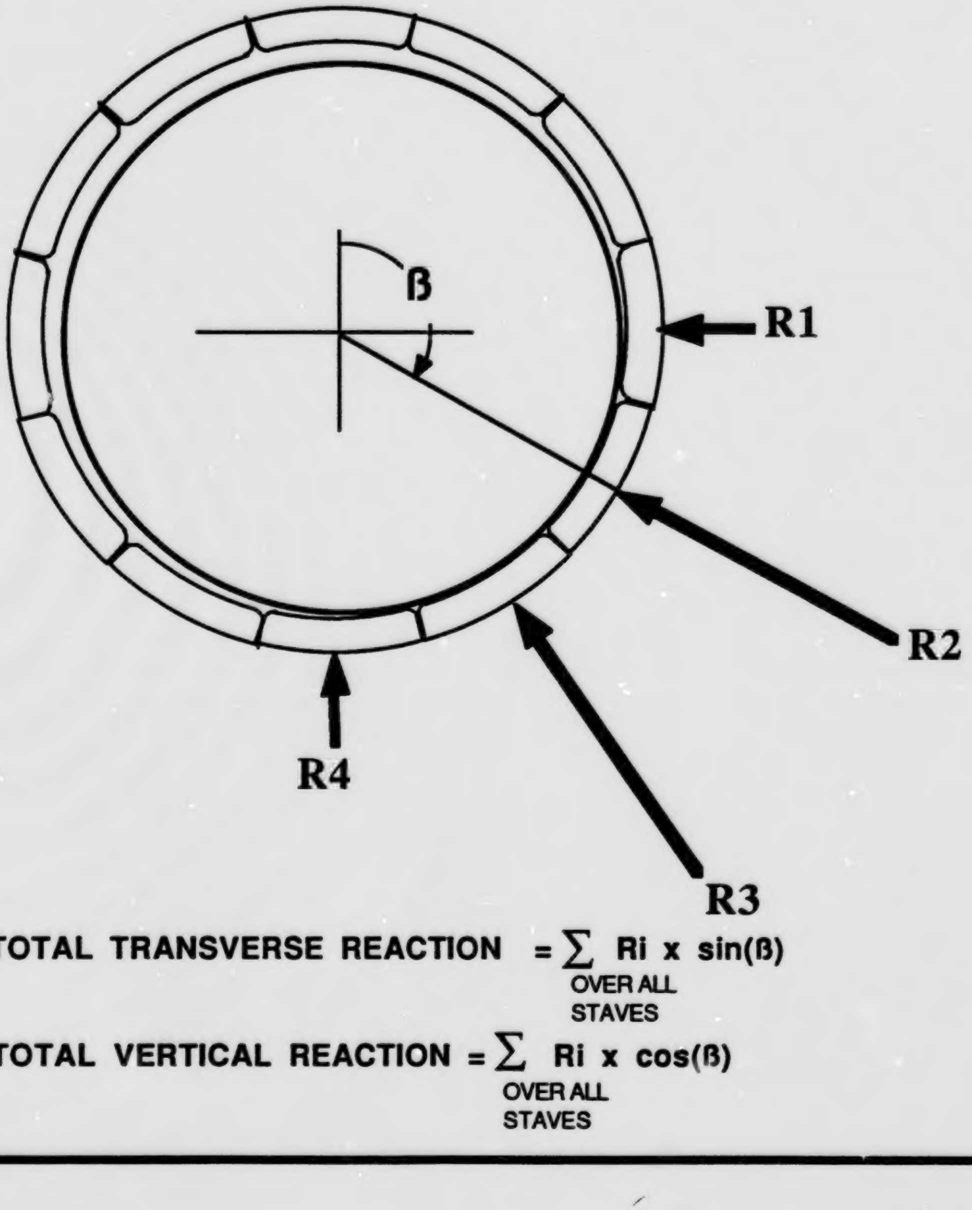


Figure 6.4.3 Calculation of Reaction/Unit Length at One Gauge Location



$$\text{TOTAL TRANSVERSE REACTION} = \sum_{\substack{\text{OVER ALL}\\ \text{STAVES}}} \text{Ri} \times \sin(\beta)$$

$$\text{TOTAL VERTICAL REACTION} = \sum_{\substack{\text{OVER ALL}\\ \text{STAVES}}} \text{Ri} \times \cos(\beta)$$

Figure 6.4.4 Illustration of Calculation of Total Reaction at a Transverse Location

5) TOTAL VERTICAL AND HORIZONTAL REACTION OF THE FORWARD BEARING - As the reaction at only one longitudinal location is known, a constant reaction/unit length distribution is assumed longitudinally. The total reaction is calculated by multiplying the reaction at the one known location by the length of the forward bearing (1.5 m).

6) TOTAL VERTICAL REACTION OF THE AFT BEARING - In the aft bearing the reaction/unit length of the bearing is known at two longitudinal locations. A linear distribution connecting these two points is assumed (Figure 6.4.5). In cases when the two known points are extrapolated and a give a tensile reaction a zero reaction/unit length is applied over that portion of the bearing.

7) TOTAL HORIZONTAL REACTION OF THE AFT BEARING - The horizontal reaction distribution is more complicated to predict as the shaft orientation and position effects the type of distribution that is valid. For the most part a linear distribution between the two known points is assumed and extrapolated to the bearing ends. The exception to this rule is if the vertical distribution predicts no vertical reaction, shaft is assumed not to be touching the bearing and the transverse reaction/unit length is set to zero as illustrated in Figure 6.4.6.

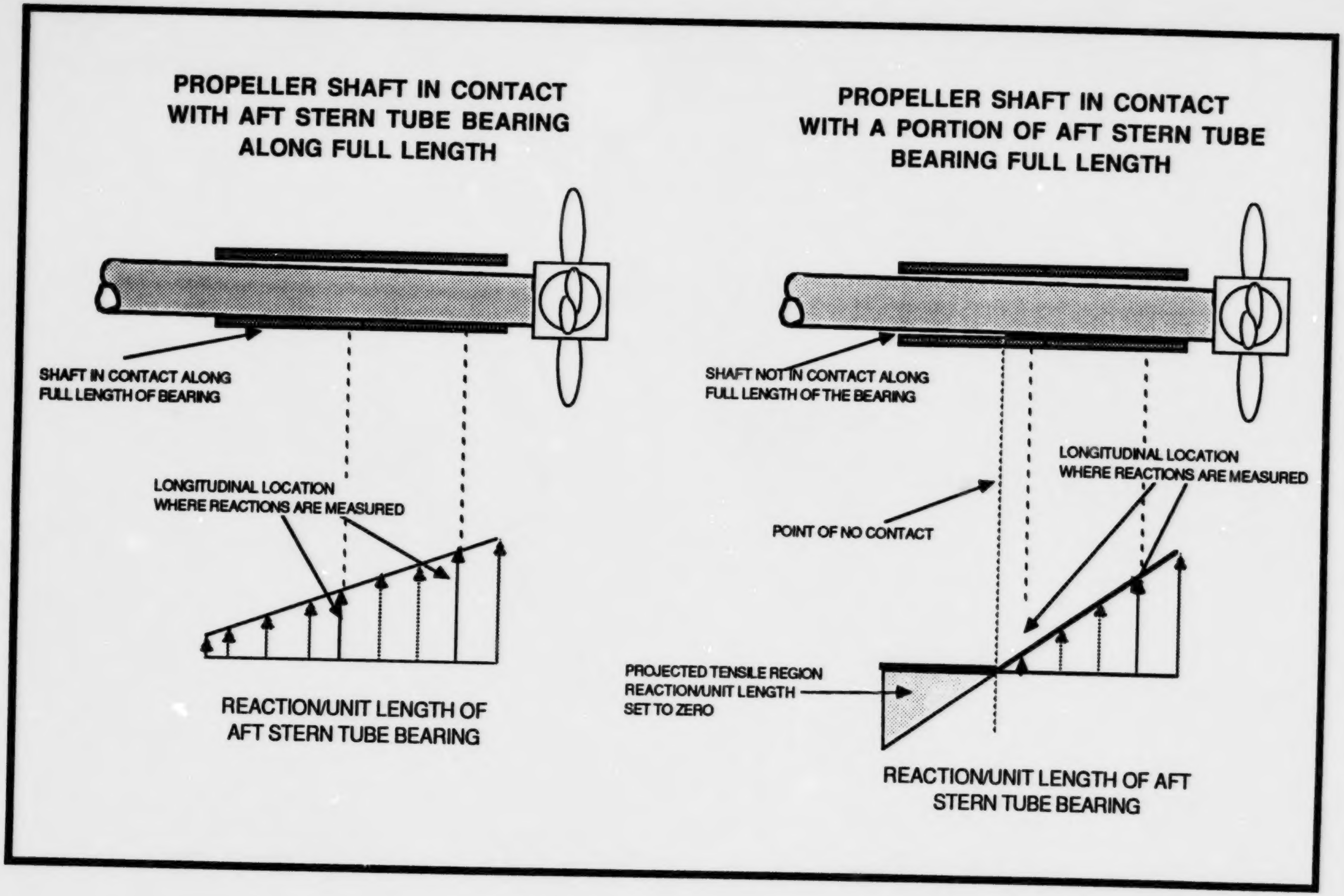

PROPELLER SHAFT IN CONTACT WITH AFT STERN TUBE BEARING ALONG FULL LENGTH
SHAFT IN CONTACT ALONG FULL LENGTH OF BEARING
LONGITUDINAL LOCATION WHERE REACTIONS ARE MEASURED
REACTION/UNIT LENGTH OF AFT STERN TUBE BEARING
PROPELLER SHAFT IN CONTACT WITH A PORTION OF AFT STERN TUBE BEARING FULL LENGTH
SHAFT NOT IN CONTACT ALONG FULL LENGTH OF THE BEARING
LONGITUDINAL LOCATION WHERE REACTIONS ARE MEASURED
POINT OF NO CONTACT
PROJECTED TENSILE REGION REACTION/UNIT LENGTH SET TO ZERO
REACTION/UNIT LENGTH OF AFT STERN TUBE BEARING

Figure 6.4.5 Longitudinal Distribution Along Aft Stern Tube Bearing

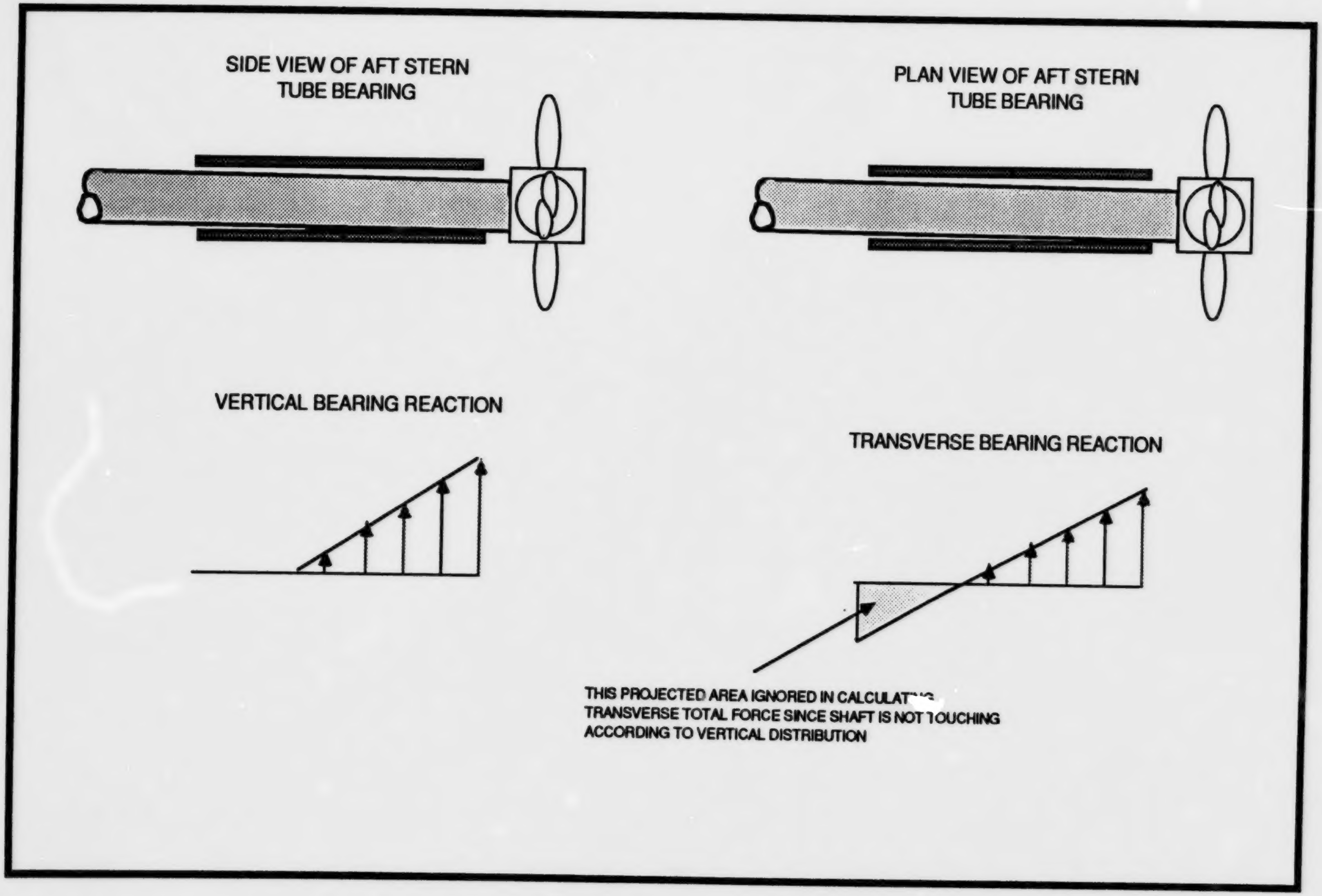

SIDE VIEW OF AFT STERN
TUBE BEARING
PLAN VIEW OF AFT STERN
TUBE BEARING
VERTICAL BEARING REACTION
TRANSVERSE BEARING REACTION
THIS PROJECTED AREA IGNORED IN CALCULATING
TRANSVERSE TOTAL FORCE SINCE SHAFT IS NOT TOUCHING
ACCORDING TO VERTICAL DISTRIBUTION

Figure 6.4.6 Exception to Standard Transverse Reaction Distribution when Shaft is not in Contact Along its Full Length Vertically

Bearing Reaction Distribution in Open Water

Figures 6.4.7a and 6.4.7b illustrate a typical total reaction time history for the open water condition for the forward and aft bearing. Figures 6.4.8a and 6.4.8b illustrate a 3-D representation of the pressure at each gauge location and the longitudinal and horizontal reaction distribution along the bearing at intervals of 0.026 seconds or 1/4 of the corresponding blade passing rate.

In open water there is little change in the reaction distribution with time. The longitudinal distribution shows maximum reaction at the aft end of the stern bearing as expected since the center of gravity of shaft and blades is near the bearing aft end. The total vertical reaction of the forward bearing is 0.15 MN and on the aft bearing 0.68 MN. The measured value of the total force on the aft bearing is within 10% of the value calculated from static alignment. The value of the total force on the forward bearing is 30% higher than calculated from the static alignment. This overprediction is due to the assumed linear distribution across the bearing. The true distribution is a trapezoid but since only one data point is available the best estimate is a linear distribution.

The aft stern tube bearing reaction has a mean angle of reaction of -5 degrees with oscillations about the mean of +/-3 degrees. This indicates that in open water the shaft equilibrium position in the aft bearing is 5 degrees to port (inboard) which is consistent with journal bearing theory. The oscillations about the mean occur at the blade passing rate. This is consistent with the commonly observed variation in shaft torque and thrust as the blades pass into and out of the uneven wake distribution caused by the ships hull and propeller skeg.

The time history of the resultant angle of reaction for the forward stern tube bearing reaction shows a value of 0 +/-10 degrees. This is an over prediction of the "travel" of the reaction due to numerical instability in calculating the arc tangent of a small number (transverse reaction) by a larger number (vertical reaction). The true shaft movement at the forward end of the forward bearing are 0 +/-2 degrees as measured by the proximity probes and shown in Figure 6.4.9.

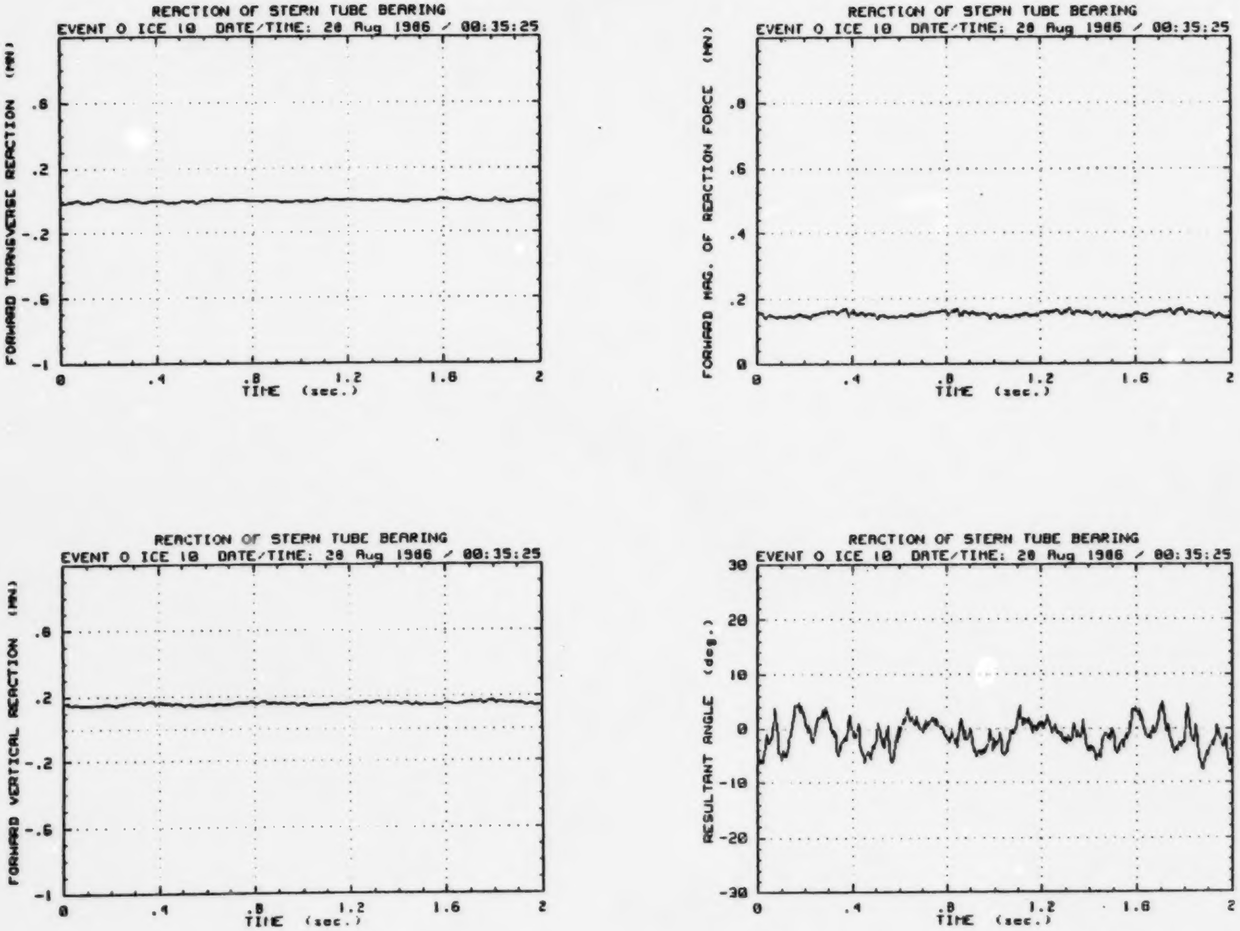


Figure 6.4.7a - Time History of Forward Stern Tube Bearing Transverse, Vertical, Total Magnitude and Resultant Angle of Bearing Reaction for Open Water Condition

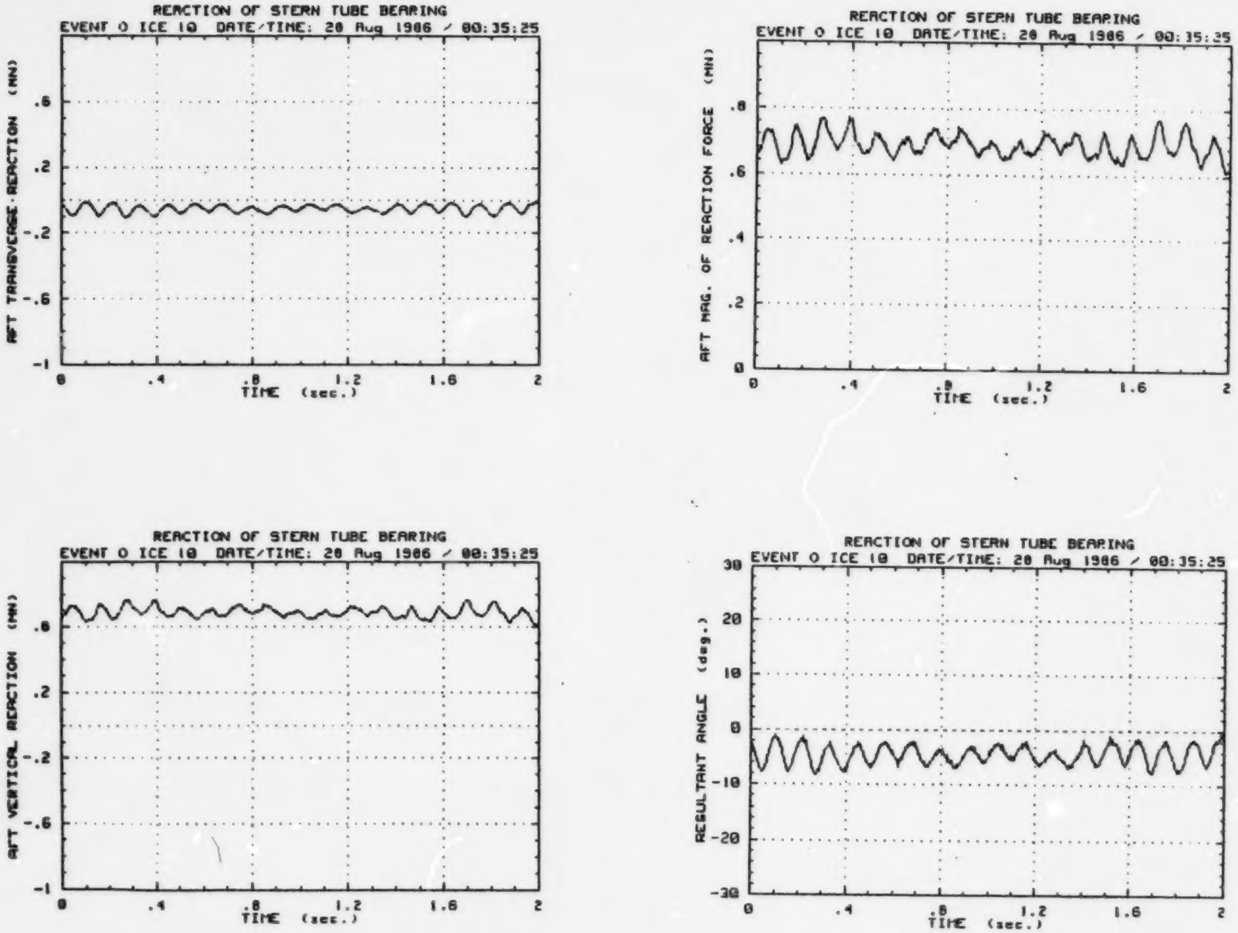


Figure 6.4.7b - Time History of Aft Stern Tube Bearing Transverse, Vertical, Total Magnitude and Resultant Angle of Bearing Reaction for Open Water Condition

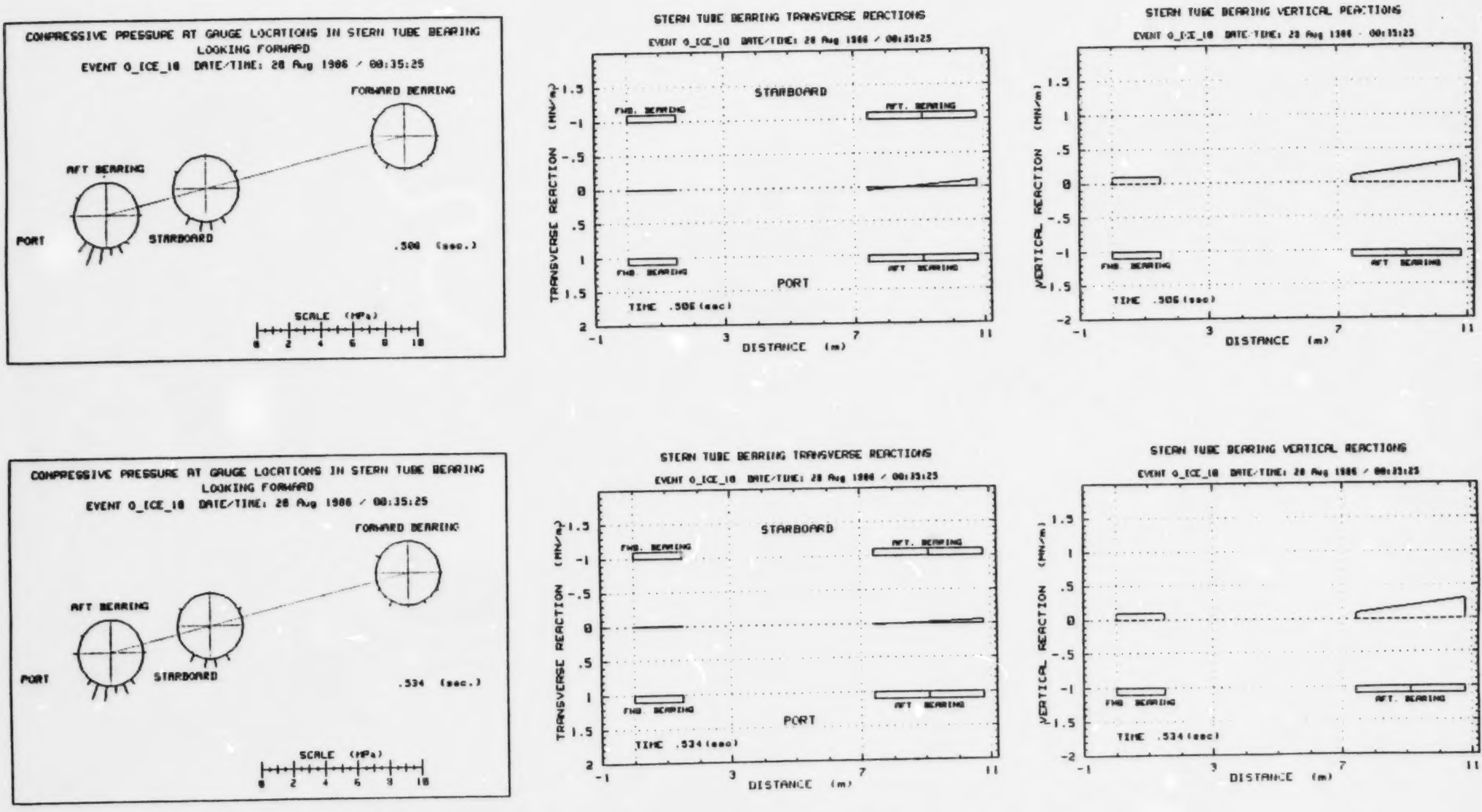


Figure 6.4.8a - 3-D Pressure Distribution at Gauge Locations with Corresponding Transverse and Longitudinal Reaction Distributions for Open Water Condition for Time steps t=0.506 and 0.534 seconds

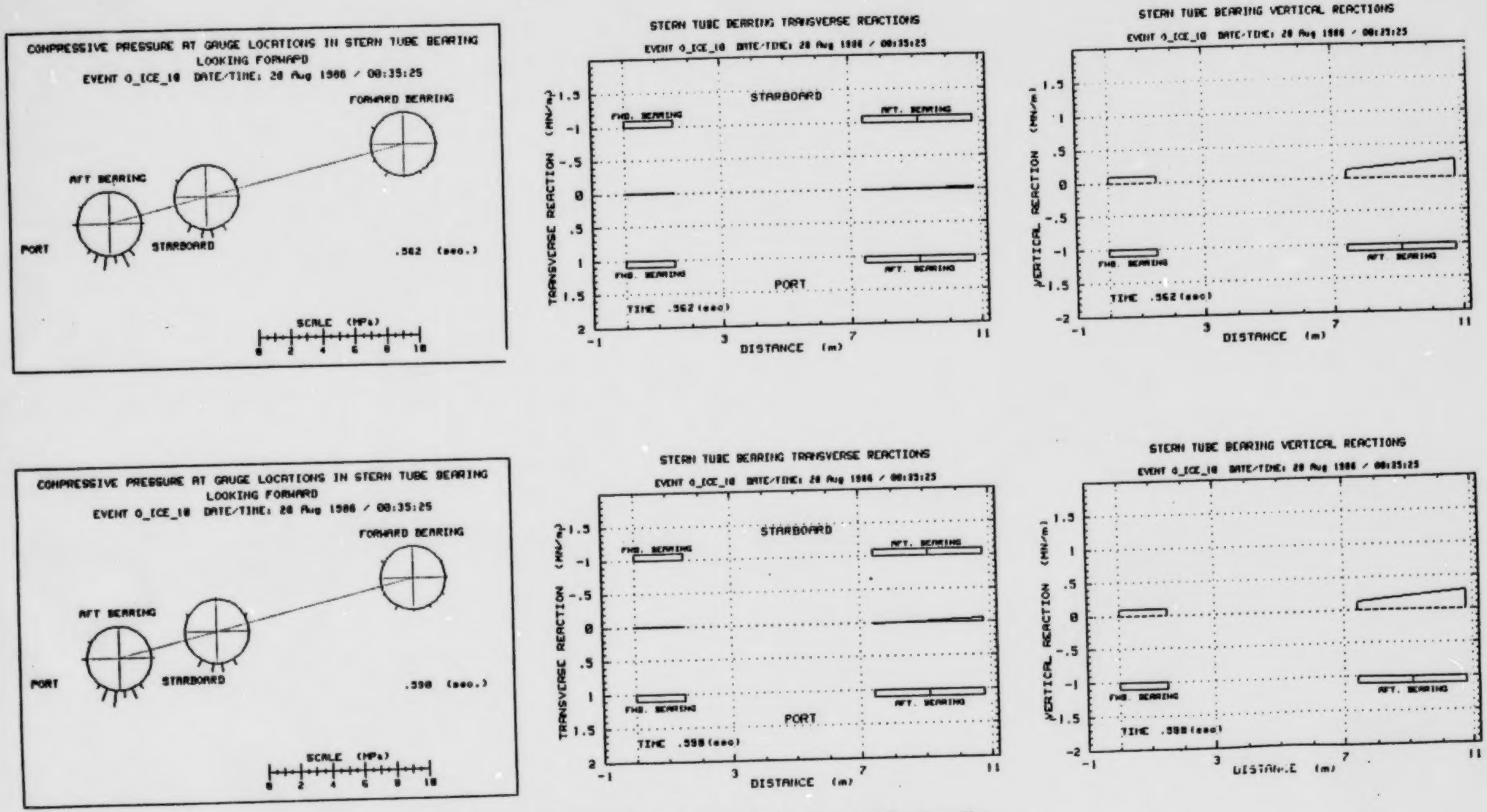


Figure 6.4.8b - 3-D Pressure Distribution at Gauge Locations with Corresponding and Longitudinal Reaction Distributions for Open Water Condition for Time steps t=0.562 and 0.590 seconds

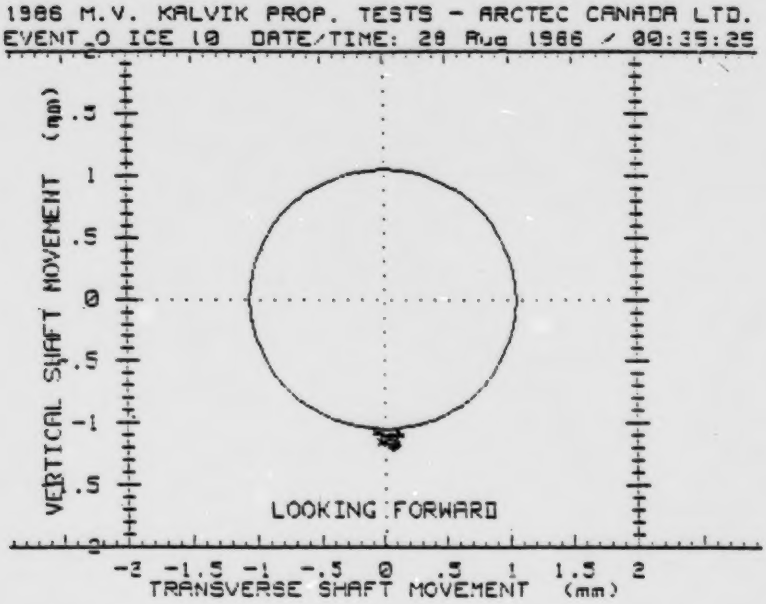


Figure 6.4.9 Shaft Movement - Open Water
Event O_ICE_10

Detailed Analysis of Event O_ICE_10

Event O_ICE_10 on 29 August at 00:35 is analysed in detail for total bearing reaction and distribution. This event is chosen because it is representative of the typical ice milling events recorded and has a maximum number of strain gauges operational at that time.

Local Pressure on the Staves

The instrumentation (strain gauge) placed in the stave measures the local pressure at that gauge. Figure 6.4.10a shows a typical time history of the pressure at one location in the aft end at the 5 o'clock position looking forward. For the first 2 seconds the propeller blades are ice free and the pressure on the stave oscillates slightly at the frequency of the blade rate. Between 2 and 6 seconds heavy ice milling is occurring. A peak pressure occurs each time a blade strikes the piece of ice. A scaled portion of Figure 6.4.10a is shown in Figure 6.4.10b. The rise time for the loading is 25 milliseconds and therefore the loading rate is 120 MPa/sec.

The maximum local instantaneous pressure recorded in this event at any gauge is 5 MPa (725 psi) (at the 4 o'clock position looking forward). This compares with the maximum recorded value of 7.5 MPa for all events.

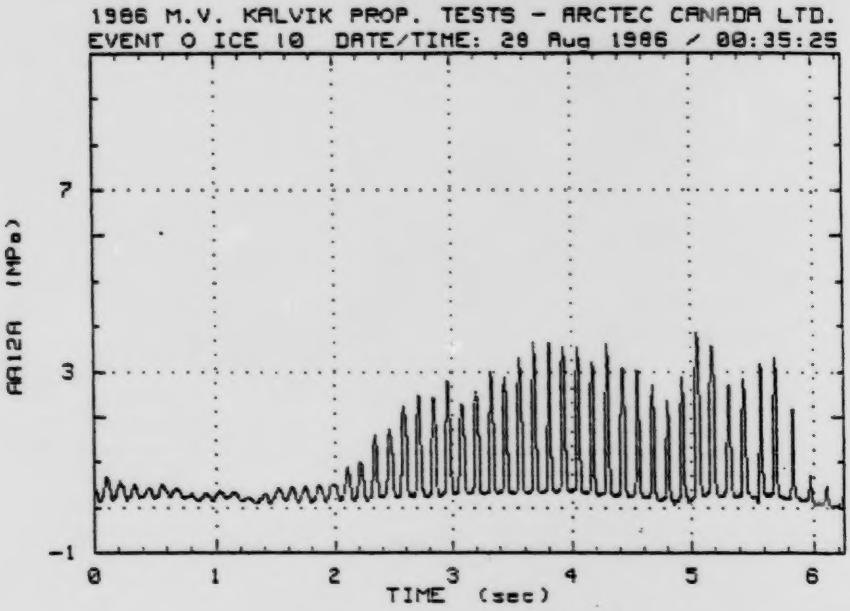


Figure 6.4.10a Typical Time History Plot of Pressure on Rubber Stave

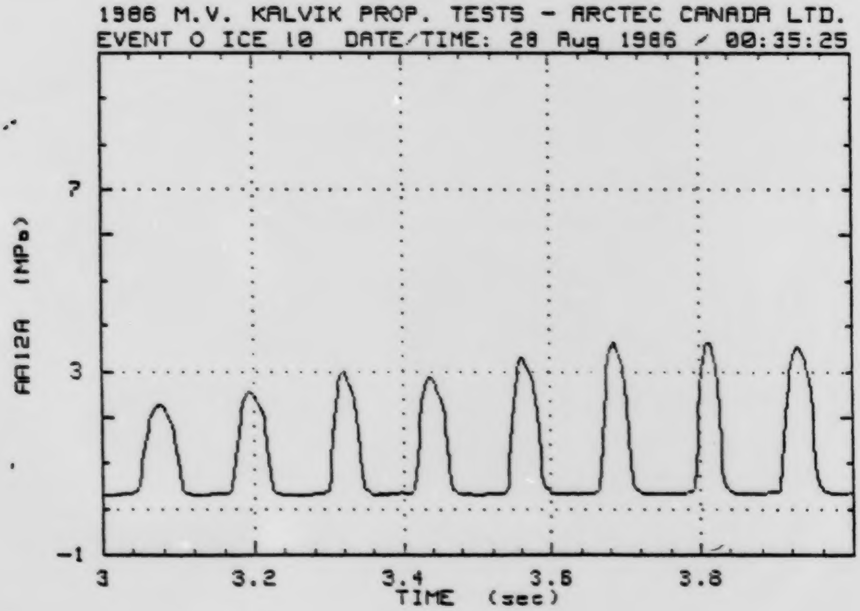


Figure 6.4.10b Typical Time History Plot of Pressure on Rubber Stave

Bearing Reaction Distribution During Ice Milling

Figure 6.4.11a and 6.4.11b shows the complete reaction time histories for a typical ice milling event. Table 6.4.2 gives a summary of the maximum reactions for this event.

Table 6.4.2
Maximum Values for Event O_ICE_10

	FORWARD BEARING	AFT BEARING
Max. Vertical Reaction	0.6 MN (~60 tonnes)	1.5 MN (~150 tonnes)
Max. Transverse Reaction	0.3 MN (~30 tonnes)	1.1 MN (~110 tonnes)
Max. Magnitude of Reaction	0.7 MN	1.55 MN (~155 tonnes)
Range of Resultant Angle	0 +/- 30 degrees	0 +/- 90degrees

The reaction time histories for the time period 5.5 to 5.8 seconds is shown in Figures 6.4.12a and 6.4.12b with vertical lines drawn at 0.014 second intervals starting at 5.558 seconds. At each of these intervals in Figures 6.4.13a to 6.4.13e, the 3-D pressure distribution at each gauge location and the longitudinal and transverse reaction distribution along the bearing is shown. From the time histories it can be concluded that the piece of ice is at 6 to 8 o'clock position (below of and inboard of the propeller hub).

The initial impact of the shaft on the bearing at t=5.558 seconds, is centered on the 4 o'clock stave. The shaft then "falls" down the bearing to the bottom of the bearing for t=5.558 to 5.586 seconds. It is important to note that the vertical reaction shows that the shaft has flexed such that the forward end of the aft bearing is unloaded and the transverse reaction in the forward bearing and the aft bearing are of opposite direction.

From t=5.600 to 5.614, the shaft is "climbing" the inboard side of the bearing under the momentum gathered from "falling" down the other side and the full length of the aft bearing is loaded. At t= 5.614 the shaft has deflected to load the forward end of the aft bearing more than the aft end.

From just before t=5.642 to 5.656, the next propeller blade begins to strike the ice and drive the shaft outboard. At t=5.656 the shaft is just beginning to contact the starboard side of the bearing once again. At t=5.670 the reaction is again reaching the maximum 0.112 after the previous peak value.

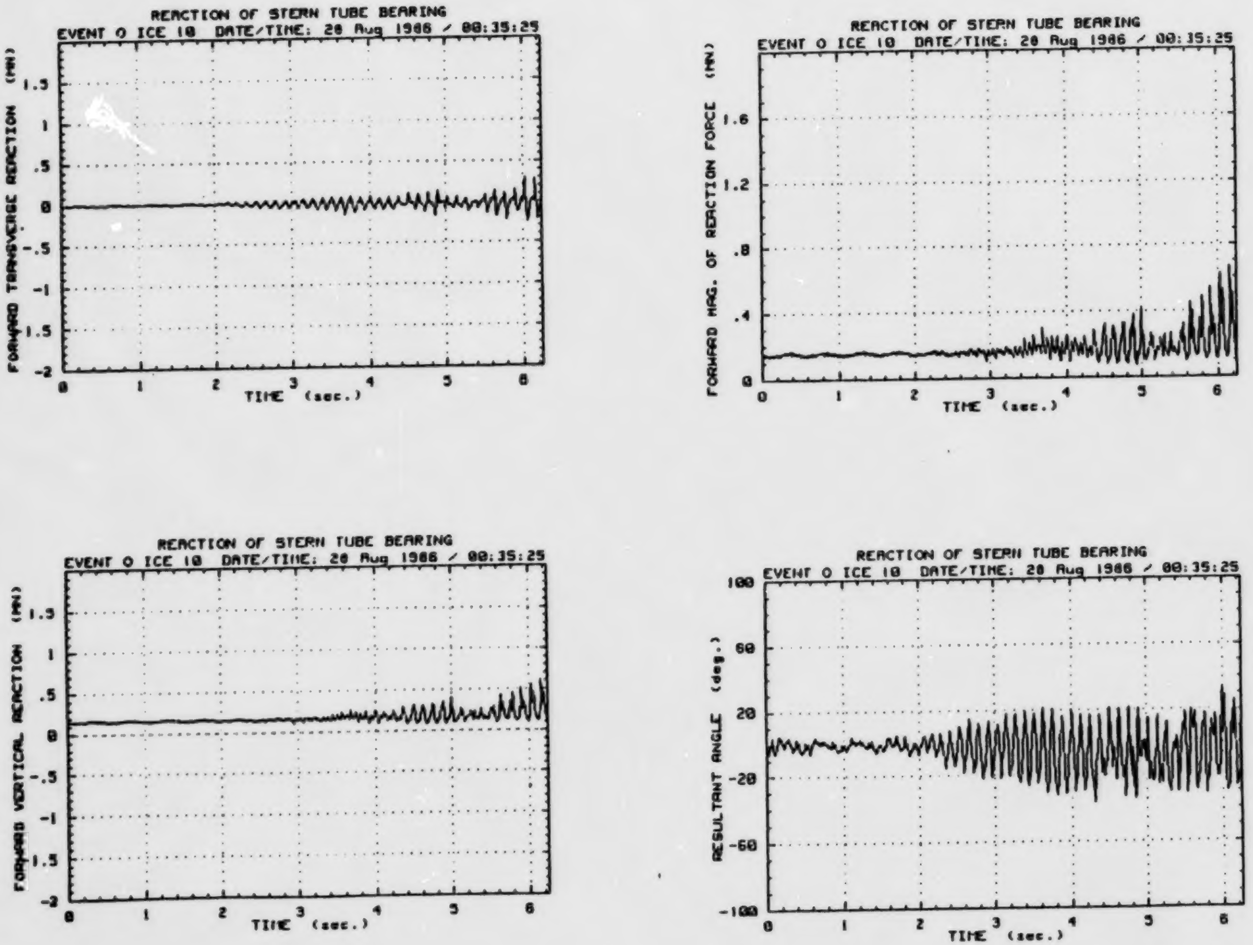

REACTION OF STERN TUBE BEARING
EVENT O ICE 10 DATE/TIME: 20 Aug 1986 / 00:35:25

Figure 6.4.11a - Time History of Forward Stern Tube Bearing Transverse, Vertical, Total Magnitude and Resultant Angle of Bearing Reaction During Ice Milling

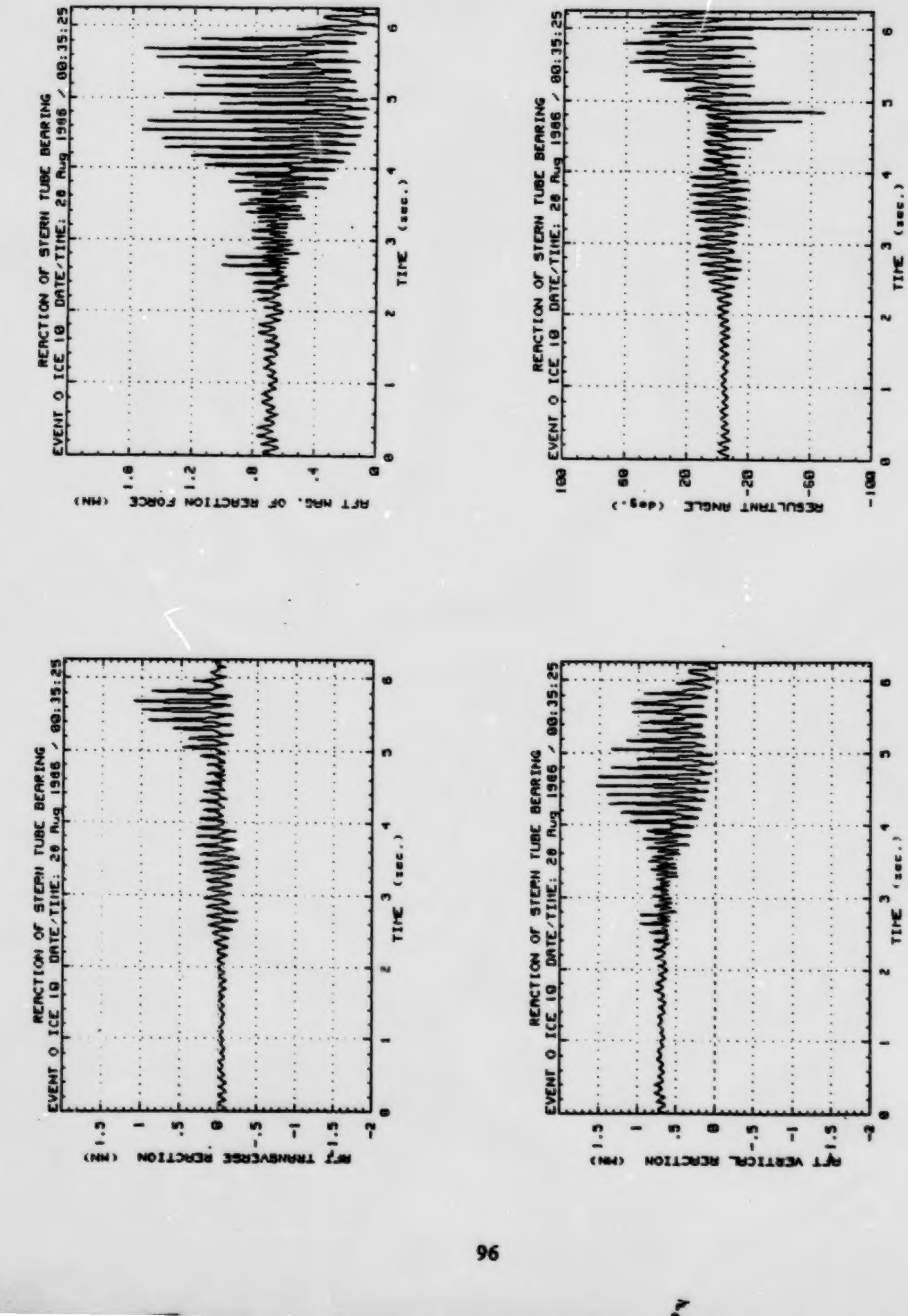


Figure 6.4.11b - Time History Aft Stern Tube Bearing of Transverse, Vertical, Total Magnitude and Resultant Angle of Bearing Reaction During Ice Milling

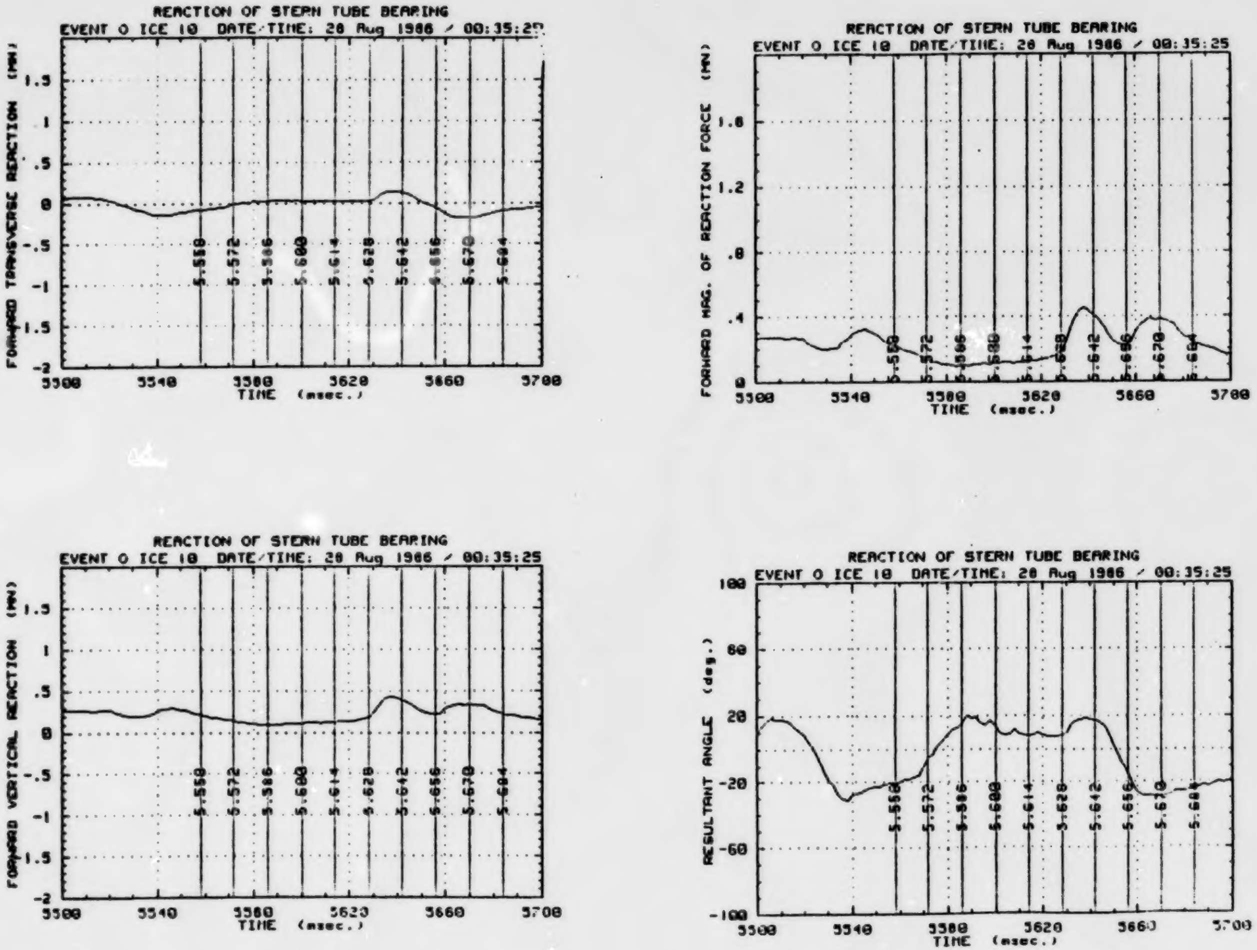


Figure 6.4.12a - Time History of Forward Stern Tube Bearing Transverse, Vertical, Total Magnitude and Resultant Angle of Bearing Reaction During Ice Milling For period t=5.5 to 5.7 seconds

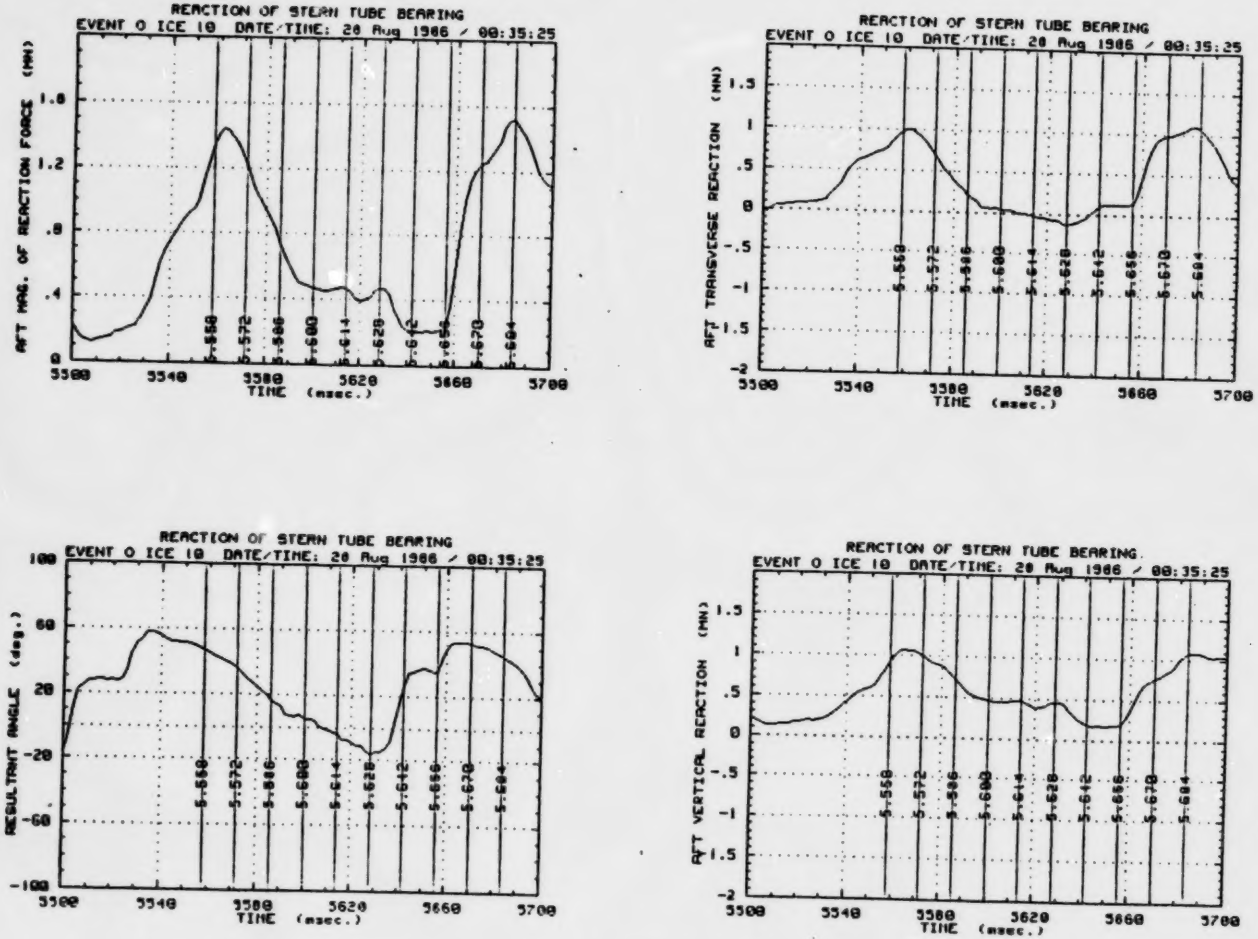


Figure 6.4.12b - Time History of Aft Stern Tube Bearing Transverse, Vertical, Total Magnitude and Resultant Angle of Bearing Reaction During Ice Milling For period t=5.5 to 5.7 seconds

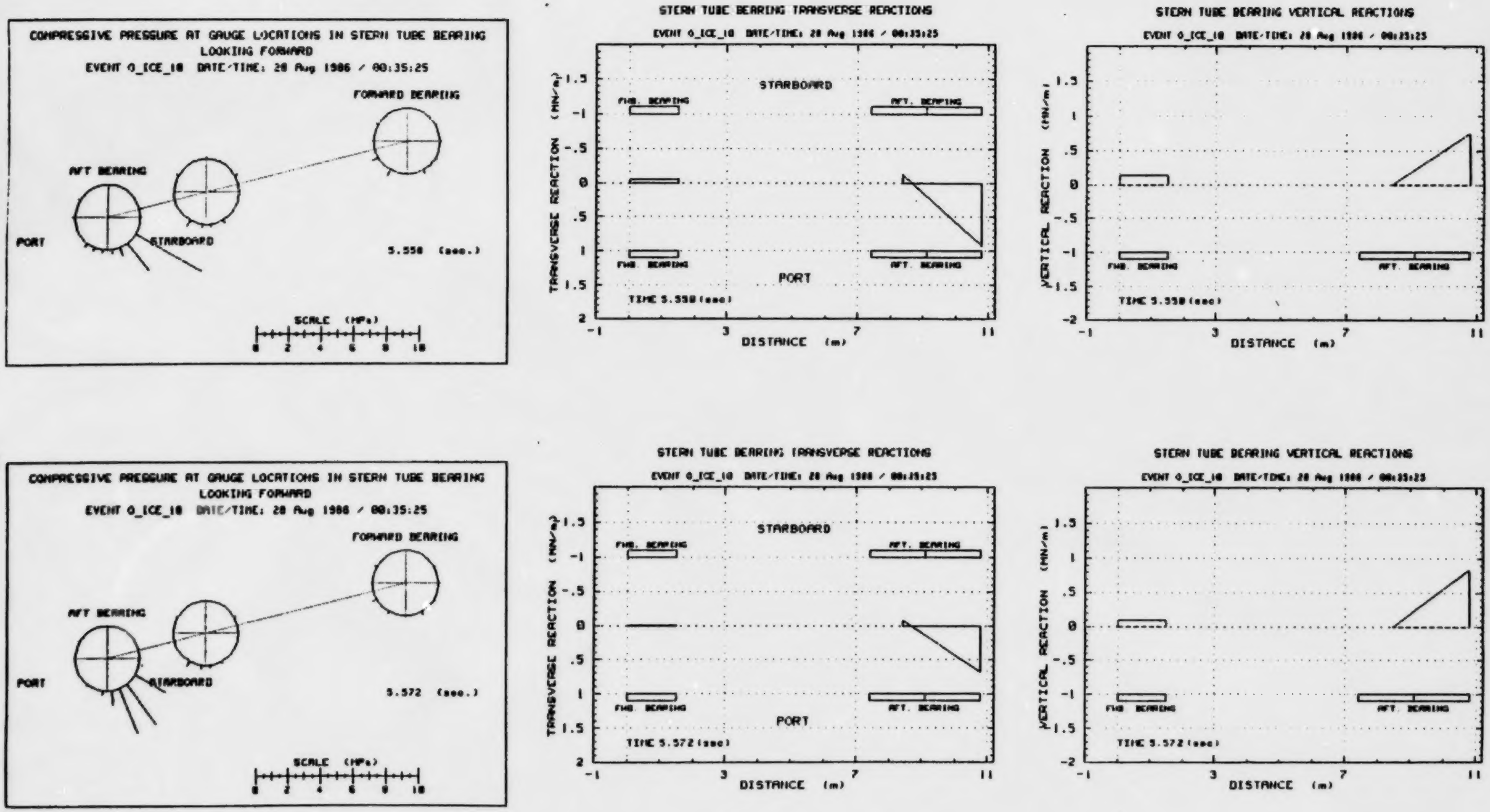


Figure 6.4.13a - 3-D Pressure Distribution at Gauge Locations with Corresponding Transverse and Longitudinal Reaction Distributions During Ice Milling for Time steps t=5.558 and 5.572 seconds

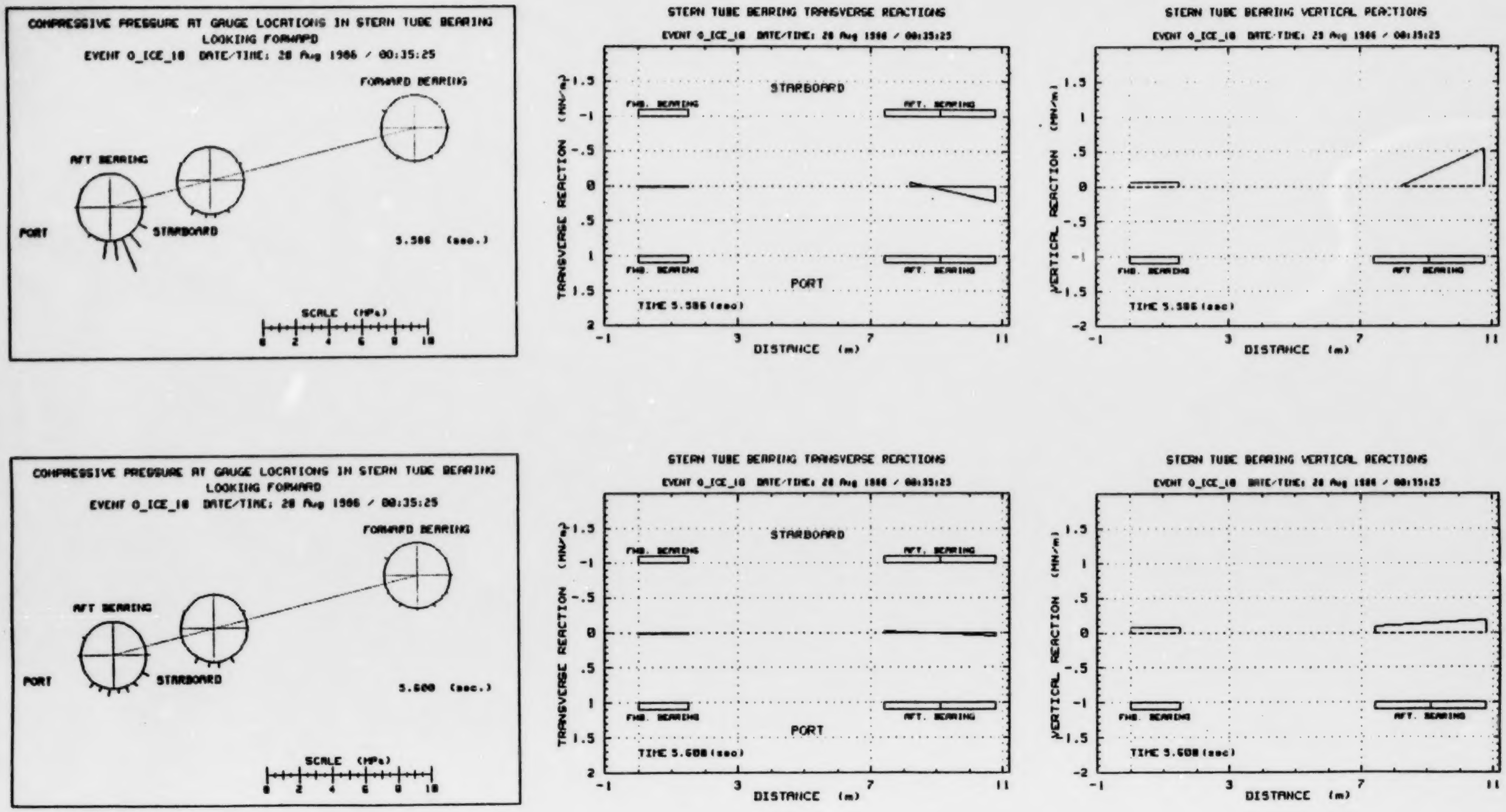


Figure 6.4.13b - 3-D Pressure Distribution at Gauge Locations with Corresponding Transverse and Longitudinal Reaction Distributions During Ice Milling for Time steps t=5.586 and 5.600 seconds

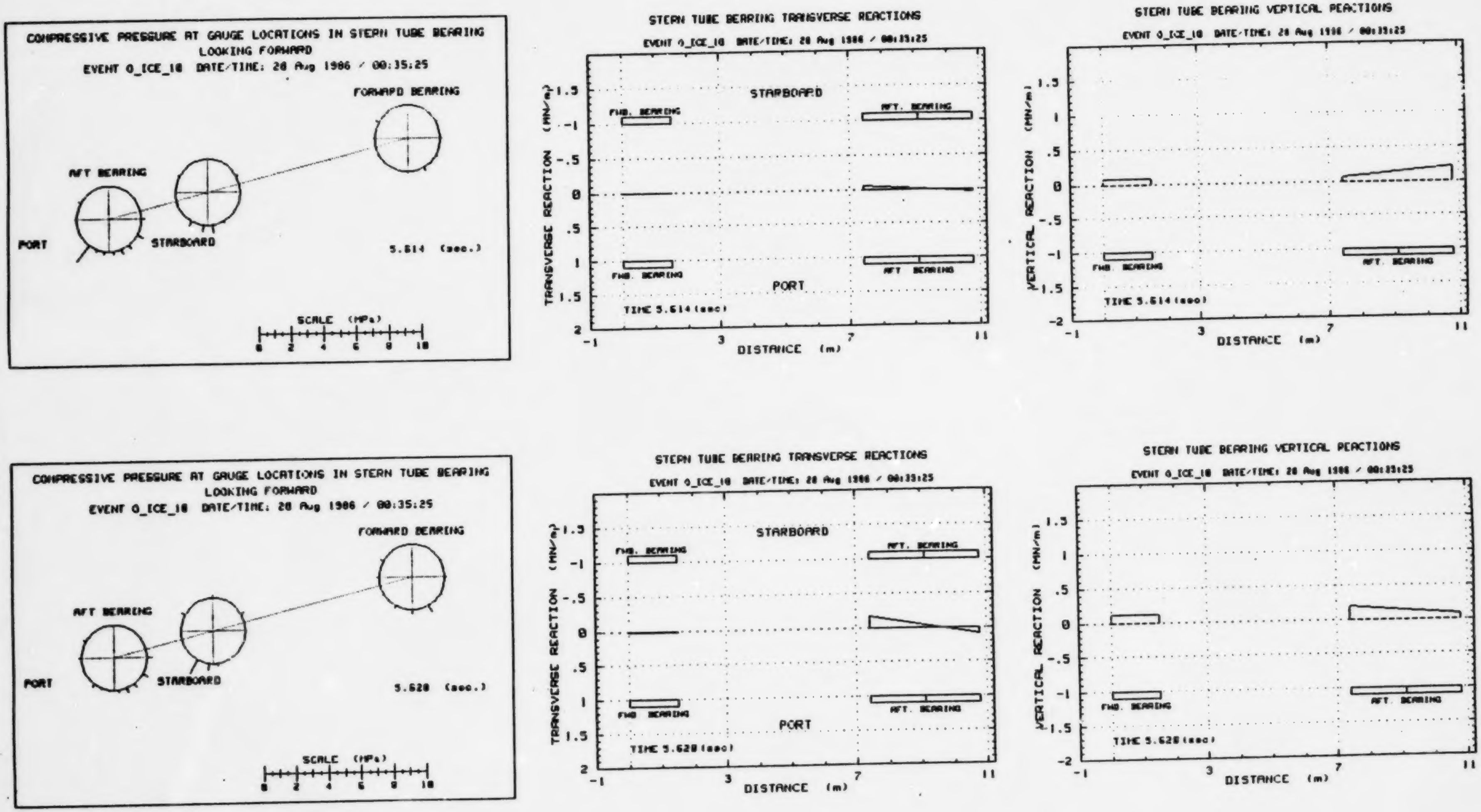


Figure 6.4.13c - 3-D Pressure Distribution at Gauge Locations with Corresponding Transverse and Longitudinal Reaction Distributions During Ice Milling for Time steps t=5.614 and 5.628 seconds

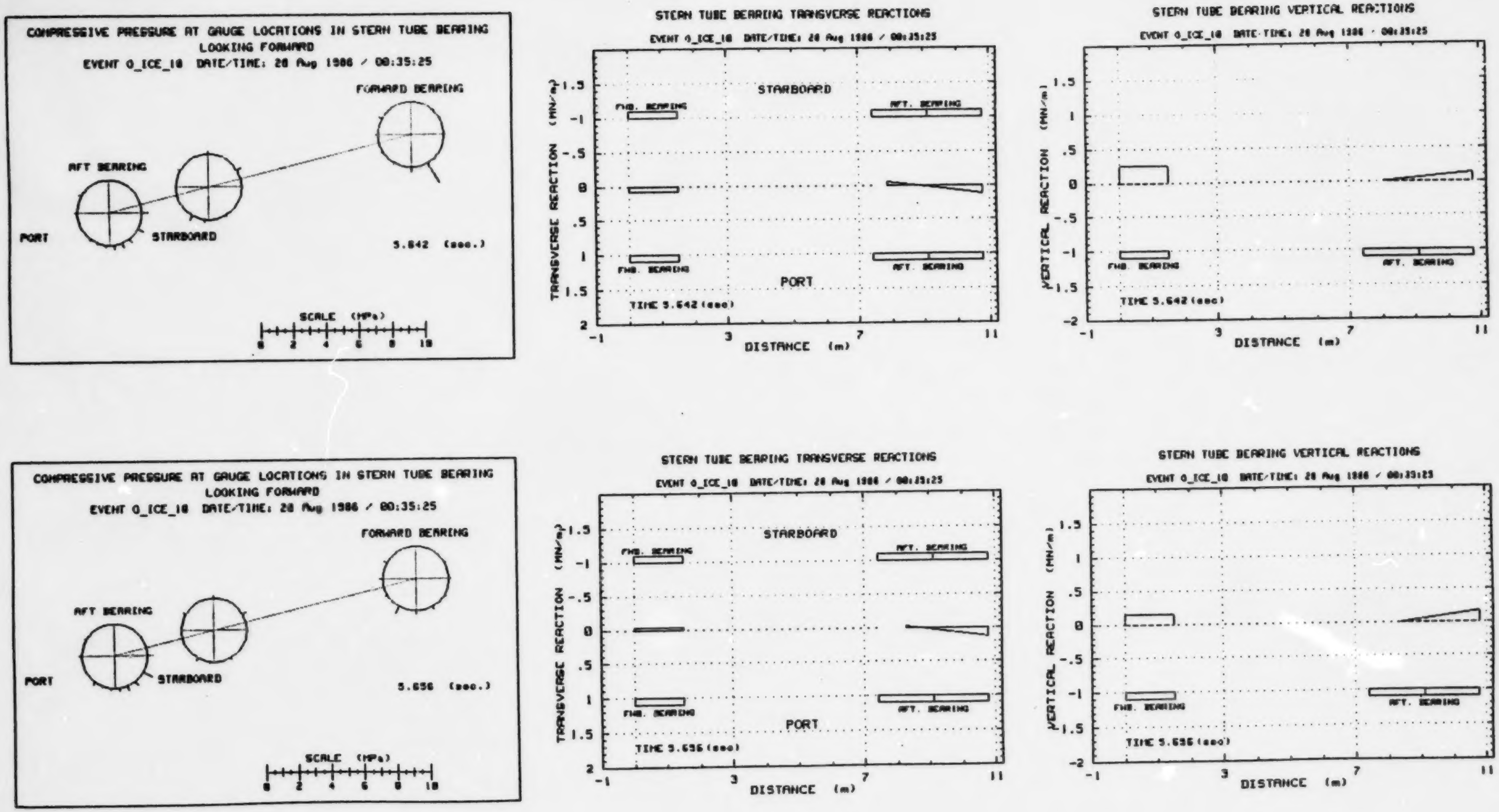


Figure 6.4.13d - 3-D Pressure Distribution at Gauge Locations with Corresponding Transverse and Longitudinal Reaction Distributions During Ice Milling for Time steps t=5.642 and 5.656 seconds

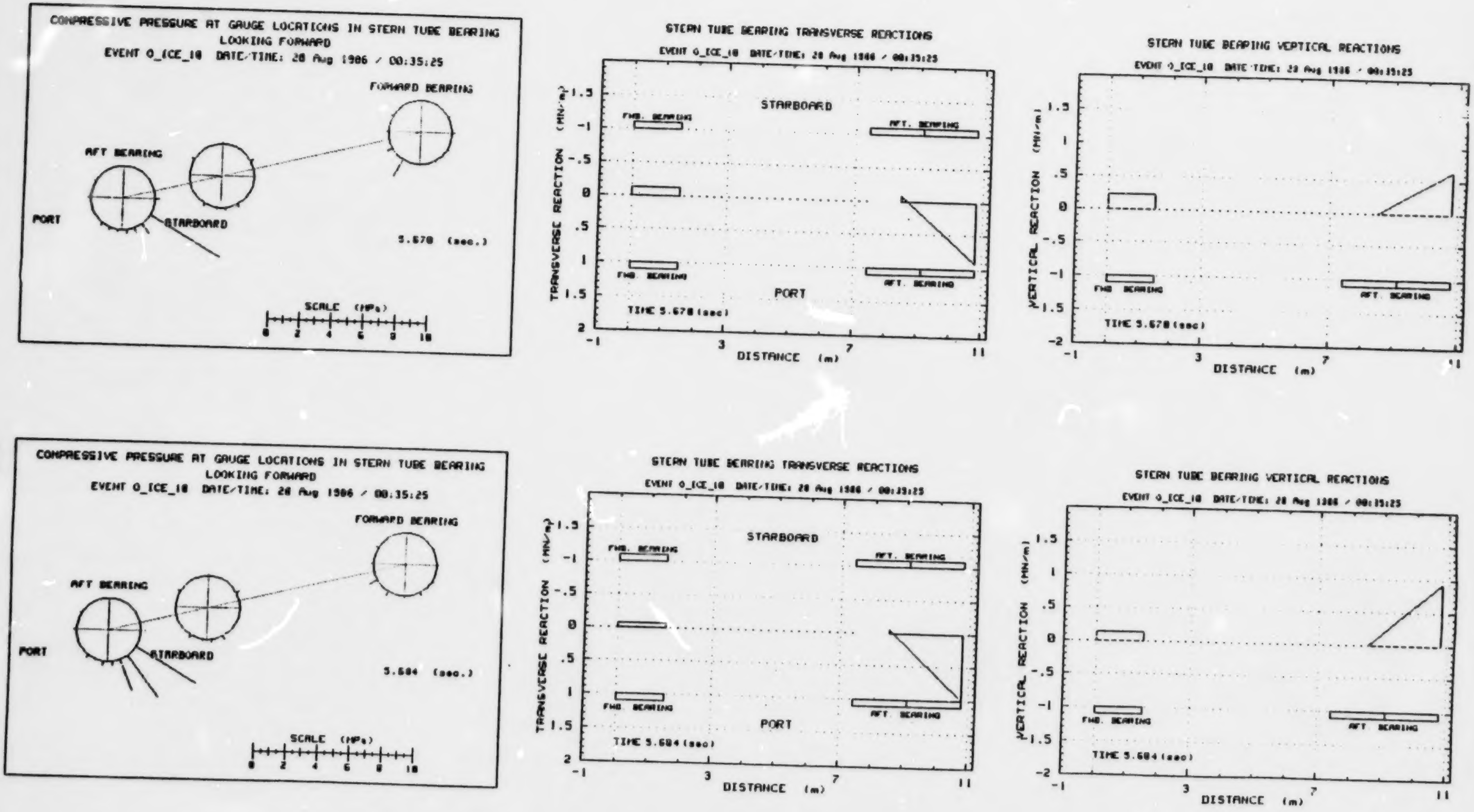


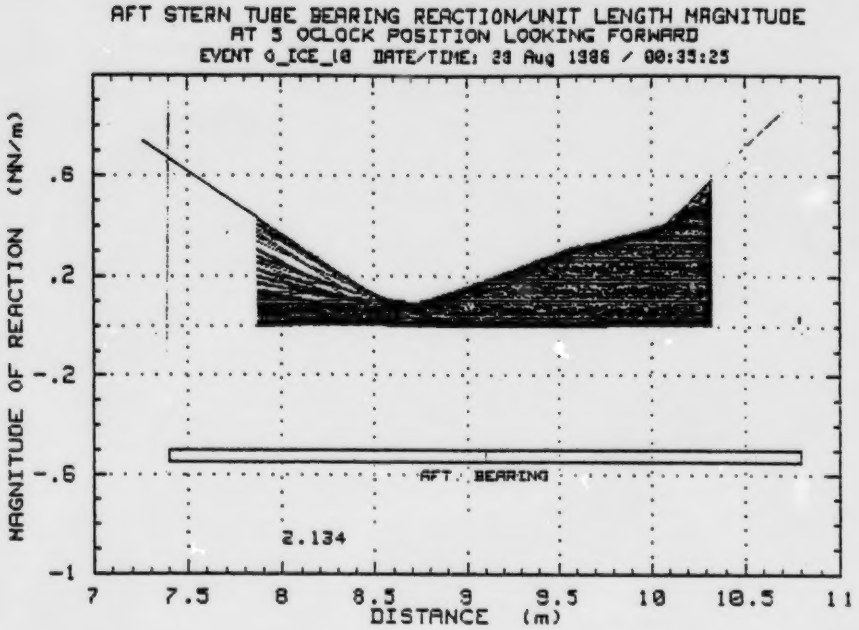
Figure 6.4.13e - 3-D Pressure Distribution at Gauge Locations with Corresponding Transverse and Longitudnal Reaction Distributions During Ice Milling for Time steps t=5.670 and 5.684 seconds

LONGITUDINAL DISTRIBUTION OF BEARING REACTION

Strain gauges were placed at 4 longitudinal locations at the 5 o'clock position in the aft stern tube bearing and at two longitudinal locations at the 7'oclock position in the forward stern tube as shown in figure 6.4.2. By connecting the known points along the stave at a specific time an instantaneous longitudinal distribution along that stave is produced.

Figure 6.4.14 illustrate the envelope of the distribution for the forward and aft bearing for event O_ice_10. It can be observed that in the aft bearing the point of minimum reaction is approximately 2 m from the aft end. The reaction at the forward end of the aft bearing is 50-75% of the value at the aft end of the bearing. The envelope of the longitudinal distribution for the forward bearing also exhibits a node of minimum reaction at the midpoint of the forward bearing.

This type of envelope is caused by the shaft being flexed up under dynamic motion of the hub and blades and then at a later instant flexing down as the hub and blades rebound as depicted in Figure 6.4.15.



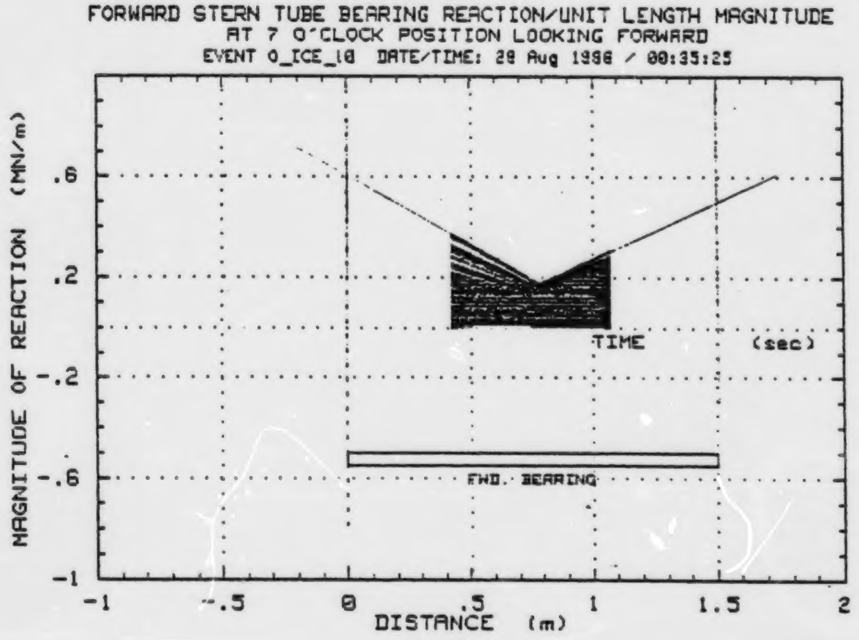


Figure 6.4.14 Reaction Distribution Envelope for Stern Tube Bearing

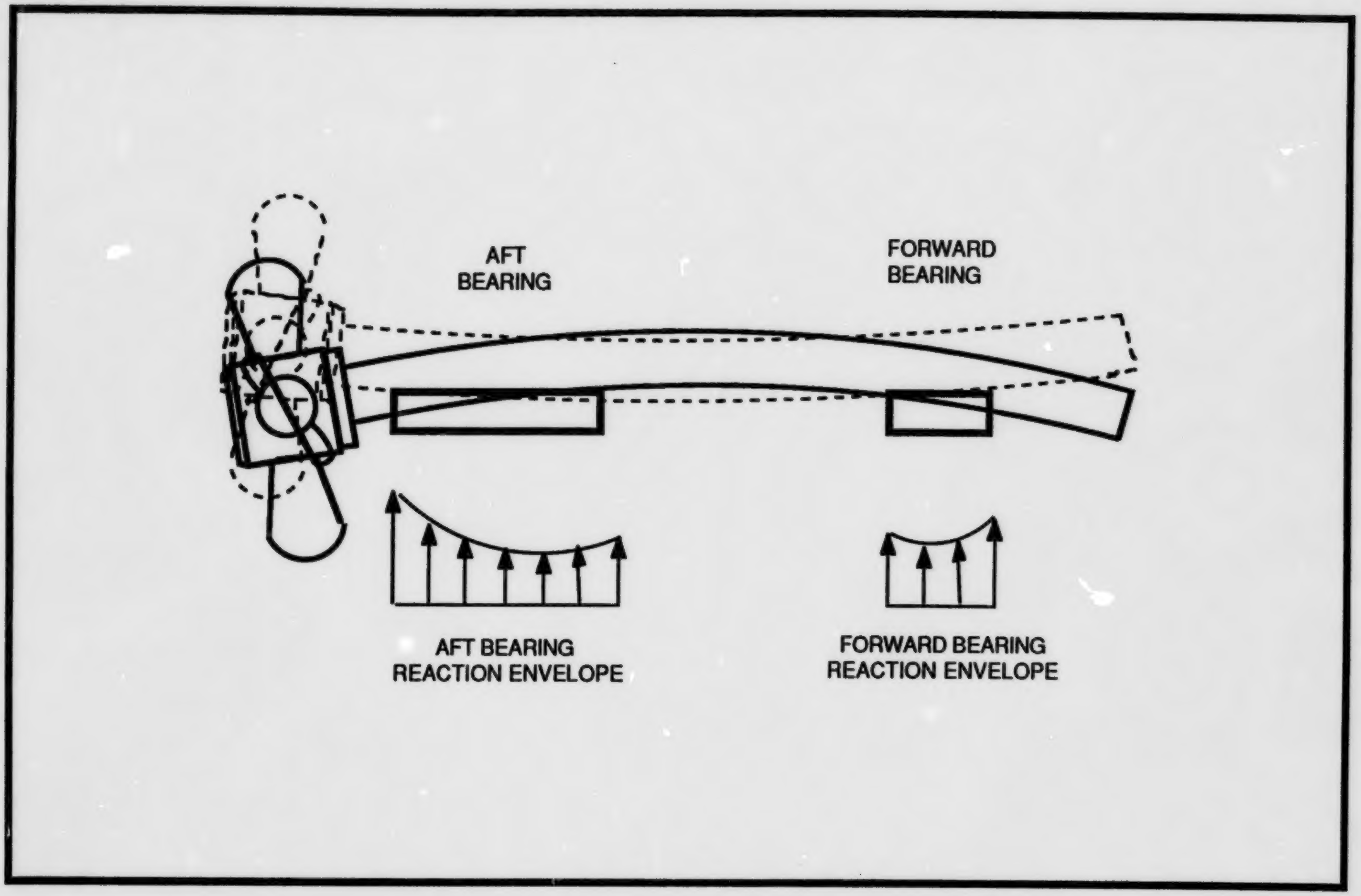


Figure 6.4.15 Longitudinal Distribution Envelope for Stern Tube Bearings

6.5 Intermediate Shaft Bearing Loads

Introduction / Summary

This section details the data analysis of the three intermediate shaft bearings full scale data. The instrumentation included gauges to measure strains due to compression of the supporting structure of each intermediate shaft bearing. These strain gauges were calibrated to determine the vertical and transverse load on the intermediate shaft bearings.

Statistical analysis was done for all trial events, and detailed analysis of the time series plots was performed for selected extreme events.

There are three intermediate shaft bearings as illustrated in Figure 6.5.1, and their particulars are the following:

Length	0.62 m
Diameter	0.47 m
Maximum Continuous Rating	320. kN
Measure Static Load- Aft. Int. Bearing	110. kN
Measure Static Load- Aft. Flywheel Bearing	67. kN
Measure Static Load- Fwd. Flywheel Bearing	124. kN

The following results were obtained from the analysis:

1. Maximum vertical and transverse load measured was 240 kN (24 tonnes) and 170 kN (17 tonnes) respectively. These loads occurred on the aft intermediate bearing. The vessel was going slow ahead and severe ice milling occurred.

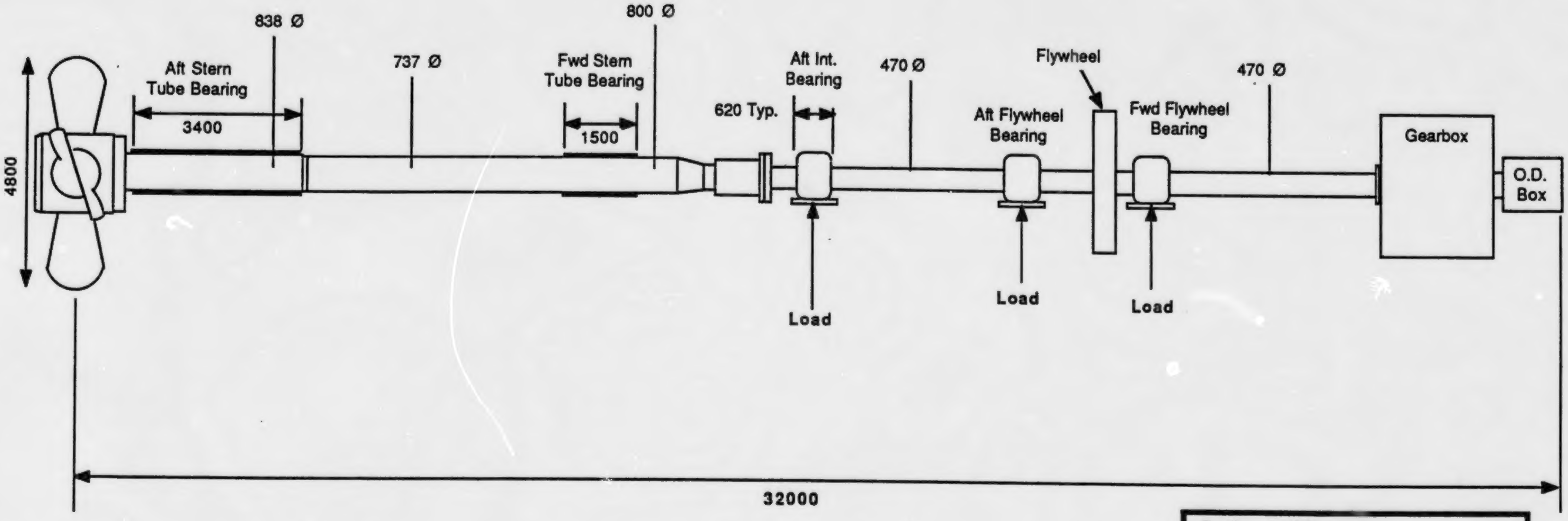
2. The maximum vertical and transverse load variation measured was +130 to -230 kN (+13 to -23 tonnes) and +/- 170 kN (+/- 17 tonnes) respectively. These loads occurred on the aft intermediate bearing and had a rise time of approximately 0.1 seconds. The vessel was going slow ahead and severe ice milling occurred.

3. The aft and the forward flywheel bearing load variation was 1/3 - 1/4 and 1/8 - 1/9 the variation of the aft intermediate bearing respectively.

Instrumentation and Measurement Procedure

A standard temperature compensated half bridge strain gauge configuration was mounted on the both sides of the supporting structure of each bearing . Figure 6.5.2 illustrates the location of the gauges and the calibration technique used. The detailed calculations of the calibration factor and associated field notes are provided in Appendix D.

The strain gauge outputs were recorded at a rate of 500 readings per second (as were all other signals) for 6.25 seconds for each event.



Scale 1:100	
Dimensions in mm	

Figure 6.5.1 Starboard Shafting - Intermediate Bearing Measurements

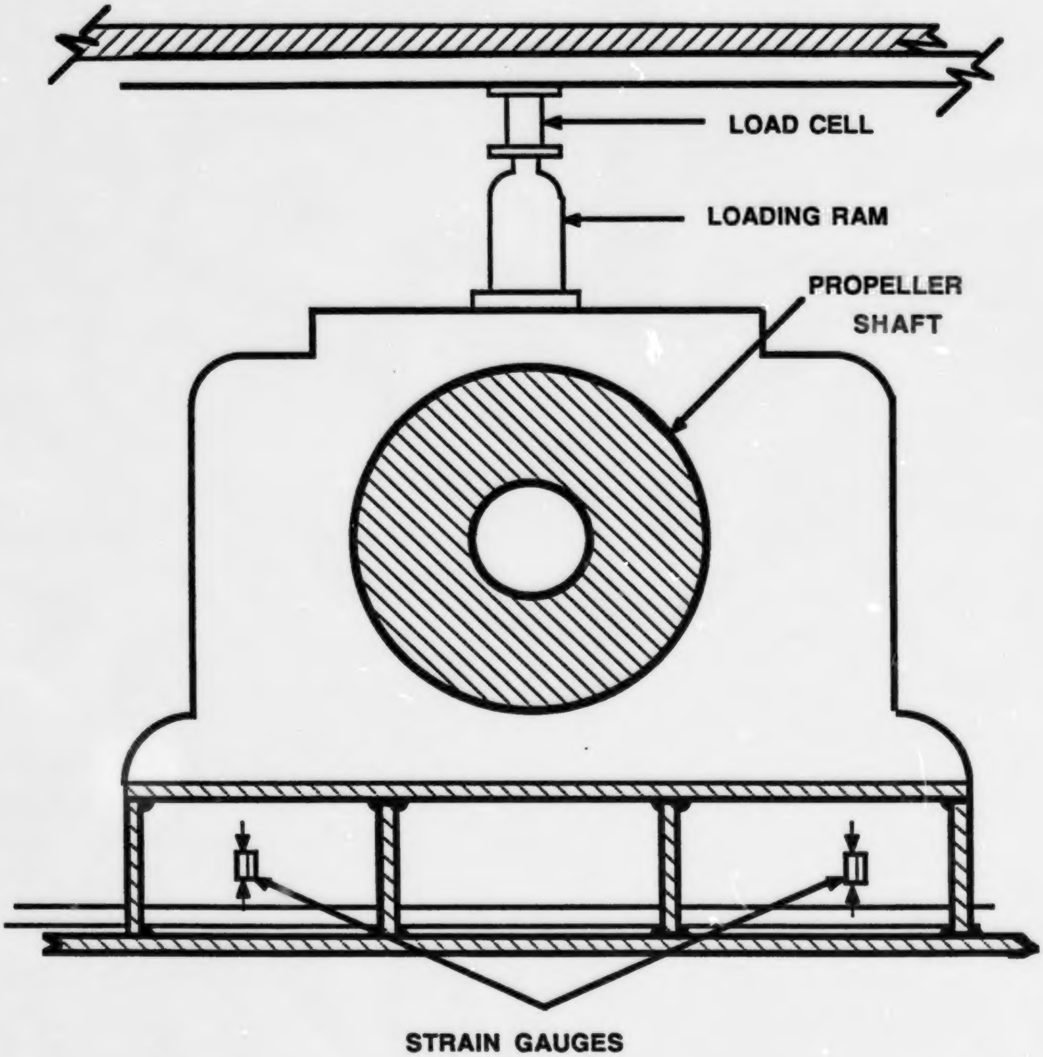


FIGURE 6.5.2
Shaft Intermediate Bearing
Calibration / Instrumentation

Data Base and Analysis Procedure

The data base for the statistical analysis includes all icebreaking events. A total of 94 valid events were identified.

The statistical analysis included calculations of the mean, maximum and minimum values of the force measured by each gauge.

Based on the statistical analysis four extreme shaft bearing load events were selected and analysed:

- Ice Milling - 2 Events
- Ice Impact - 1 Event - Maximum Shaft Torque
- Ice Impact - 1 Event - Maximum Shaft Thrust

Time series data analysed included vertical and transverse load on each shaft intermediate bearing. The resultant magnitude and direction of the load on the bearings was also calculated. The ship operation and ice conditions were also extracted from the data base. The detailed field notes and calibration calculations are provided in Appendix D.

Table 6.5.1 summarizes for each selected event the event label, the date and time, the activity category and the associated ice conditions.

Table 6.5.1 Selected Events for Intermediate Bearing Load Analysis

Event Label	Date	Time	Operation Category	Ice Conditions
TEST_09	05 Sept. 86	13:43:22	Turning to Stbd. - Icebreaking Full Ahead	2/10 old, 8/10 med. 1st yr ice, vast floes
TEST_18	07 Sept. 86	09:38:18	Turning to Stbd. - Icebreaking 3/4 Ahead	2/10 old, 8/10 med. 1st yr ice, vast floes
TEST_24	09 Sept. 86	20:21:09	Turning to Stbd. - Icebreaking Full Ahead	4/10 old, 6/10 thick, 1st yr ice, vast floes
TEST_28	12 Sept. 86	11:02:11	Slow Ahead - Icebreaking	5/10 old, 4/10 med. 1st yr ice, vast floes

Results

Result Summary

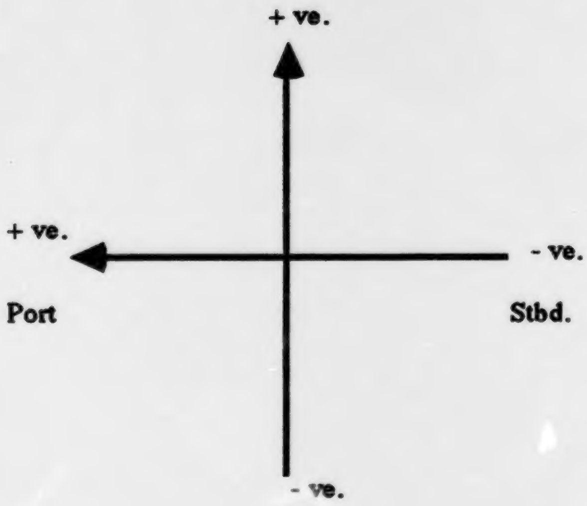
Table 6.5.2 summarizes the results of the detailed analysis for the selected extreme events as well as the open water conditions. Comments relevant to the bearing response are also listed.

Table 6.5.2 Result Summary of Intermediate Shaft Bearing Analysis

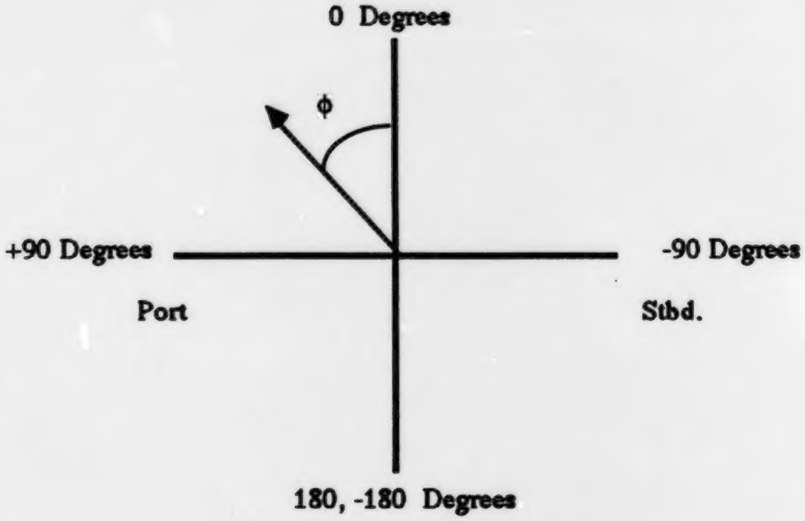
Event Label	Bearing	Maximum Loads (kN)			Comments
		Vertical	Transverse	Total	
Open Water	Aft. Int.	120.	20.	122.	Addition of
	Aft. Fly.	65.	10.	66.	Static Alignment
	Fwd. Fly.	140.	30.	124.	Reactions
Test_09	Aft. Int.	125.	140.	170.	Rudder / Ice
	Aft. Fly.	90.	60.	110.	Impact
	Fwd. Fly.	175.	35.	170.	Max. Shaft Thrust
Test_18	Aft. Int.	190.	160.	200.	Ice Milling
	Aft. Fly.	115.	60.	130.	
	Fwd. Fly.	150.	30.	150.	
Test_24	Aft. Int.	140.	140.	190.	Ice Impact
	Aft. Fly.	100.	50.	105.	1.2 Sec. Long
	Fwd. Fly.	170.	60.	170.	Max. Shaft Torque
Test_28	Aft. Int.	240.	170.	270.	Heavy Ice Milling
	Aft. Fly.	135.	80.	170.	
	Fwd. Fly.	150.	70.	170.	

Note 10 kN~ 1 Tonne

The sign convention for the intermediate bearing loads is illustrated in Figure 6.5.3.



Looking Forward
Load = Force Bearing Exerts on Shaft



Looking Forward

ϕ= Angle of Resultant Bearing Reaction

Figure 6.5.3 - Sign Convention for Intermediate Bearing Loads

Maximum Shaft Thrust - Ice Propeller Impact (Test_09)

Time history plots for the maximum thrust event measured (Test 09) of the vertical, transverse and resultant loads on all shaft intermediate bearings, as well as the direction of the applied load on the bearings, are provided in Figures 6.5.4a - 6.5.4f. These plots illustrate the reaction of the shaft bearings to a short duration impact of ice on the propeller.

The rudder was directed to the starboard from 18 degrees to 35 degrees (hard-over). The frequency of the rudder stock torque variation was at the blade rate of 8-9 Hz. as described in Section 6.3. This indicated that ice became wedged in between the rudder and the starboard propeller. The propeller milled the ice for approximately 1.8 seconds and then open water conditions resumed. The ice milling occurred between 2 and 3.8 seconds in the time history.

The maximum increase in load of 120 kN (12 tonnes) was in the transverse direction on the aft intermediate bearing. The rise time of this load was approximately 0.1 seconds and it oscillated from +140 kN to -140 kN at the blade rate of 8-9 Hz.

The direction of the resultant load on the aft intermediate bearing oscillated from -70 degrees (to starboard) to +50 degrees (to port).

The corresponding transverse load variation on the aft and forward flywheel bearing was 1/3 and 1/8 of the aft intermediate bearing respectively.

Heavy Ice Milling (Test 28)

Time history plots for one of the most severe ice milling events of the vertical, transverse and resultant load, as well as the direction of the applied load on the bearings are provided in Figures 6.5.5a to 6.5.5f. These plots illustrate the reaction of the shaft bearings to an ice milling event lasting approximately 5.5 seconds (48 blade passes).

The vessel was in ahead pitch of 10 degrees decreasing to 2 degrees. The rudder angle was varied from 4 degrees to port to 5 degrees starboard. The propeller milled the ice for approximately 5.5 seconds and then open water conditions resumed. The ice milling occurred between 0 and 5.5 seconds in the time history.

The maximum increase in load of 150 kN (15 tonnes) was in the transverse direction on the aft intermediate bearing. The rise time of this load was approximately 0.1 seconds and it oscillated from +170 kN to -170 kN at the blade rate of 8-9 Hz. The maximum vertical load increase of 120 kN (12 tonnes) was also on this bearing and it varied from +250 kN to -130 kN. The negative value in the load on the aft intermediate bearing indicated that the bearing was pulling the shaft down rather than supporting it upward.

The direction of the resultant load on the aft intermediate bearing oscillated from -180 degrees (to starboard) to +180 degrees (to port). This result indicates that the shaft was loading the bearing throughout the entire circumference.

The corresponding transverse load variation on the aft and forward flywheel bearing was 1/3 and 1/9 of the aft intermediate bearing respectively. The corresponding vertical load variation on the aft and forward flywheel bearing was 1/4 and 1/9 of the aft intermediate bearing respectively.

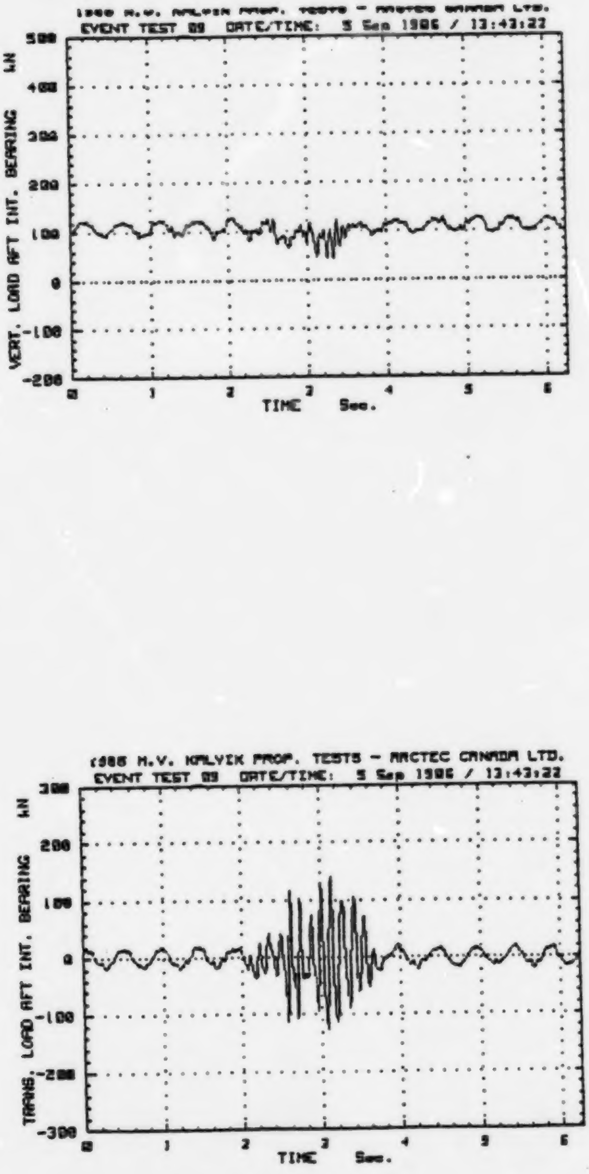


Figure 6.5.4a Response of Shaft Bearings
- Ice Propeller Impact

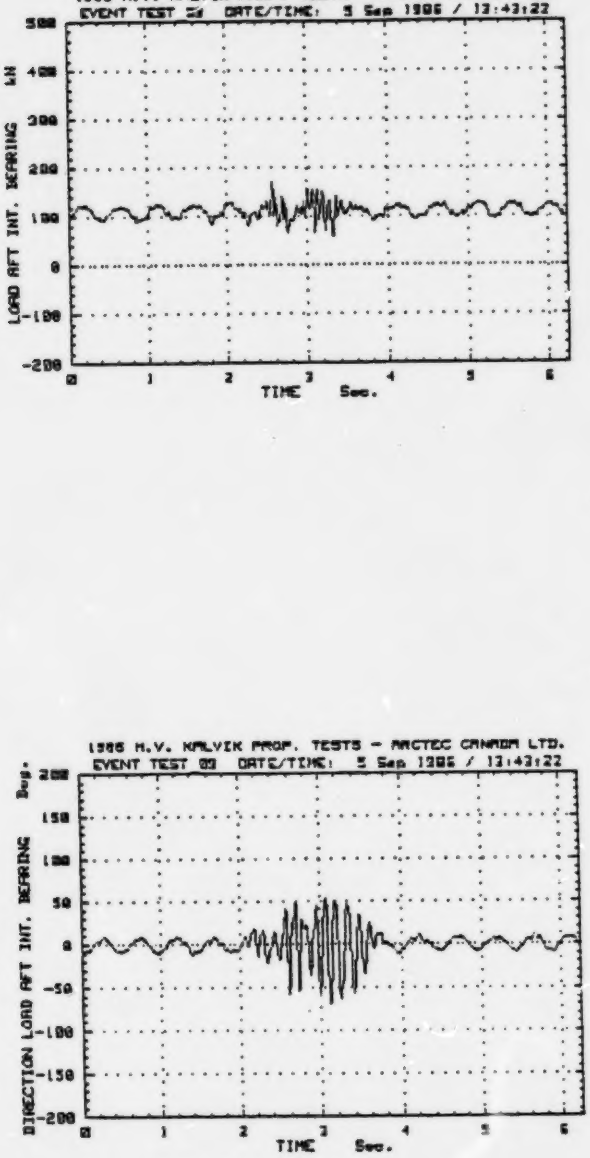
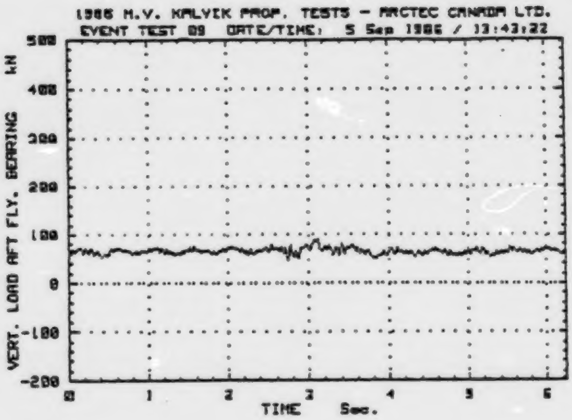


Figure 6.5.4b Response of Shaft Bearings - Ice Propeller Impact



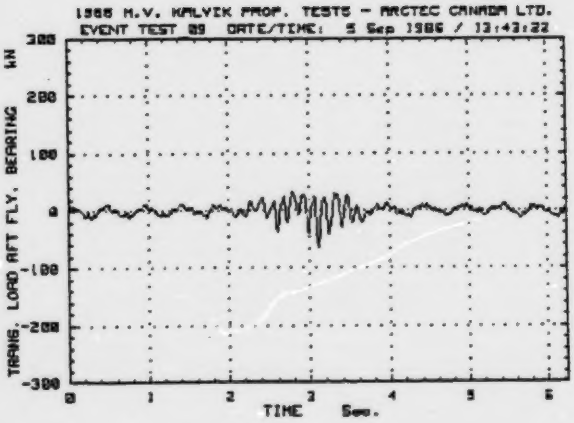


Figure 6.5.4c Response of Shaft Bearings - Ice Propeller Impact

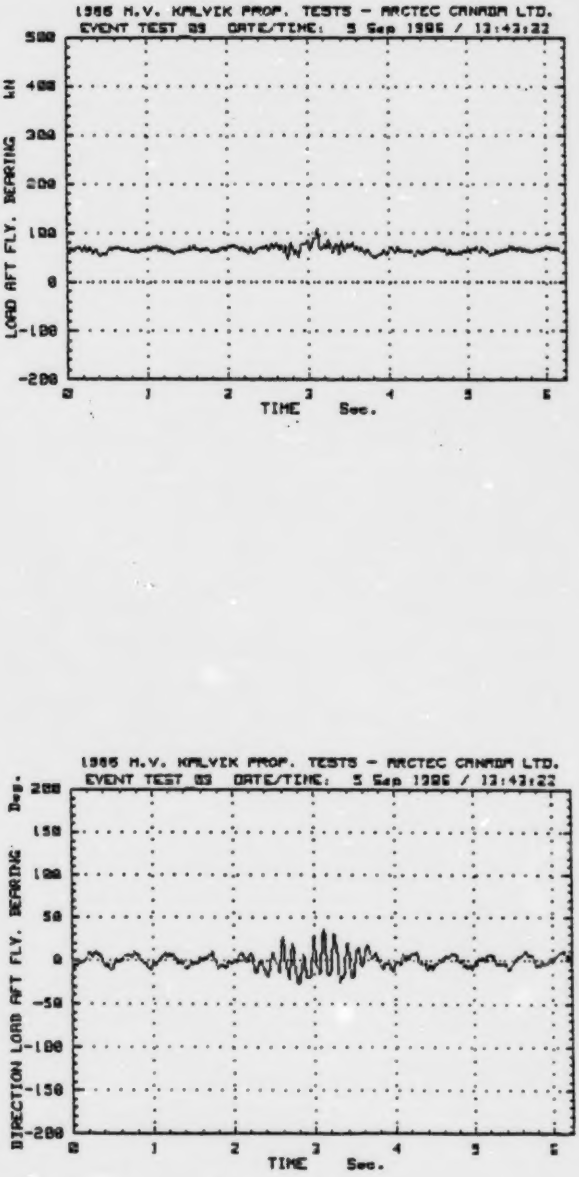


Figure 6.5.4d Response of Shaft Bearings - Ice Propeller Impact

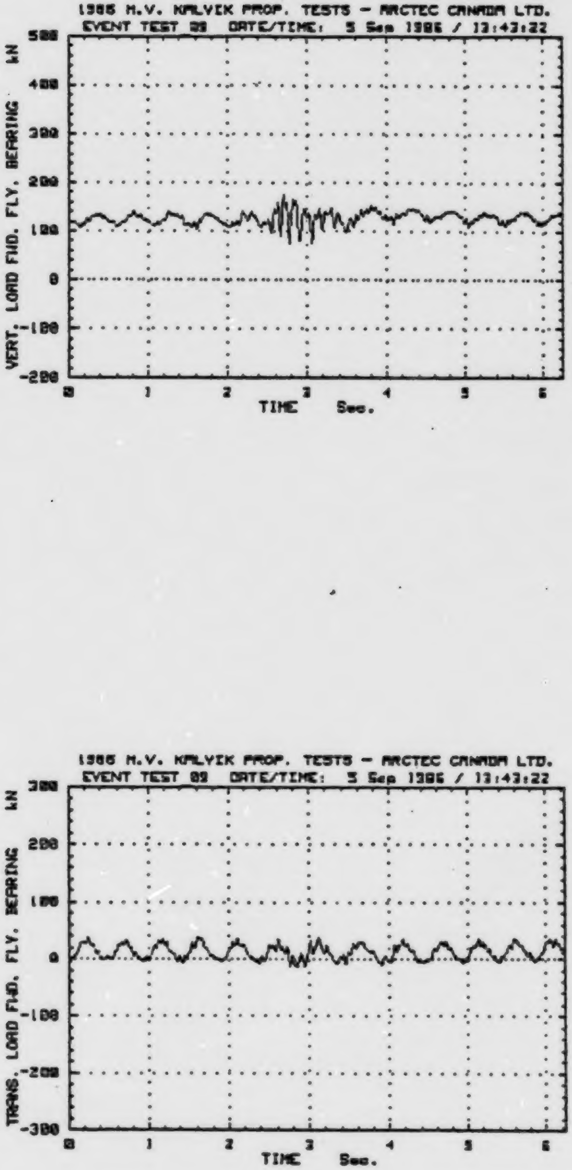
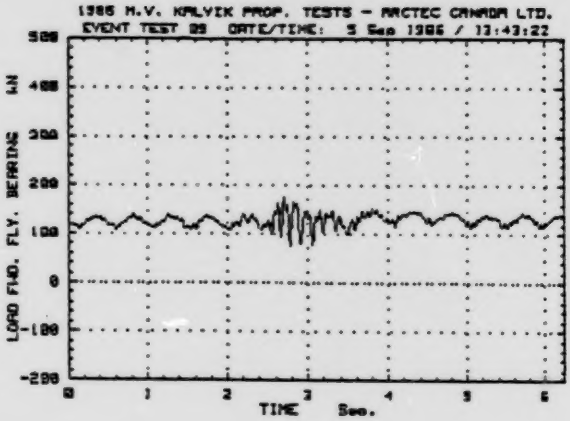


Figure 6.5.4e Response of Shaft Bearings - Ice Propeller Impact



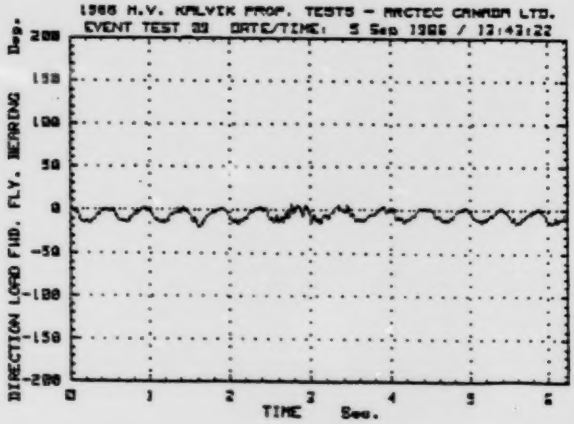


Figure 6.5.4f Response of Shaft Bearings - Ice Propeller Impact

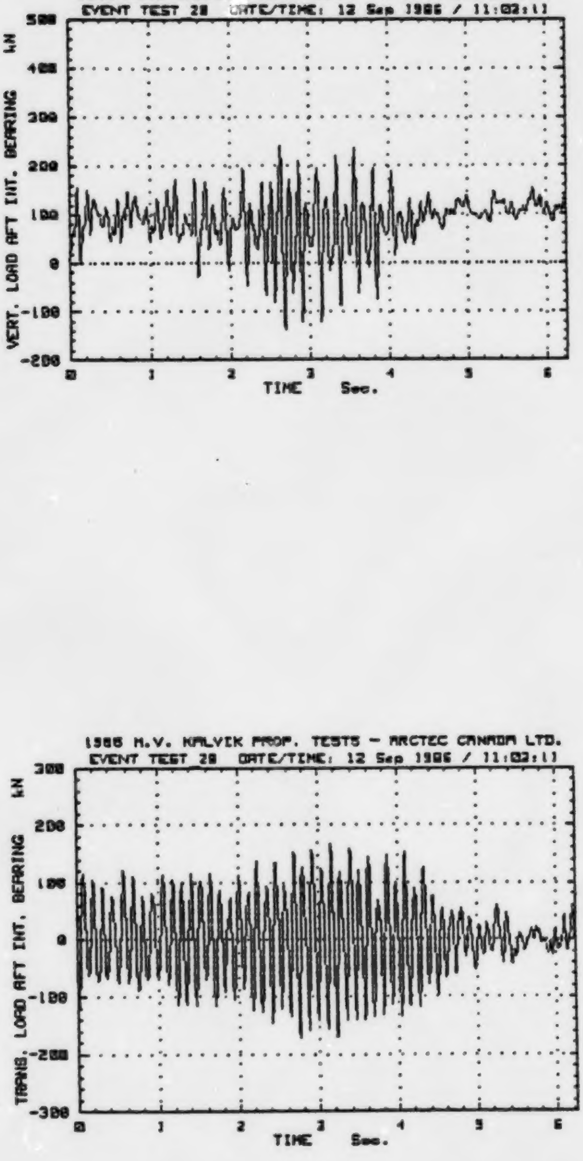


Figure 6.5.5a Response of Shaft Bearings
- Ice Milling

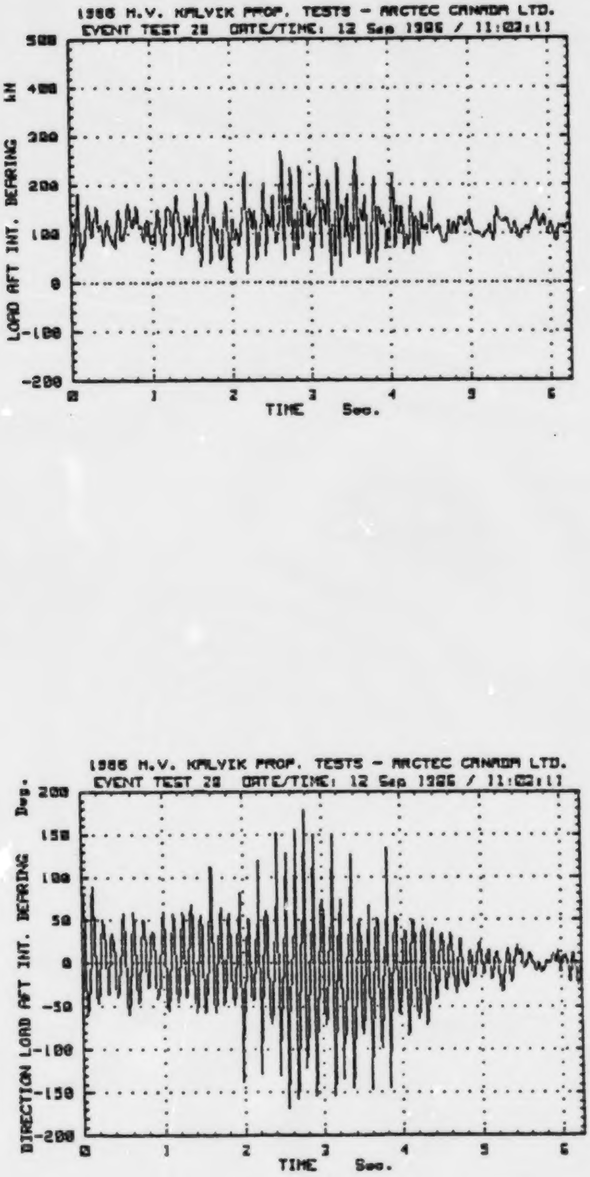


Figure 6.5.5b Response of Shaft Bearings - Ice Milling

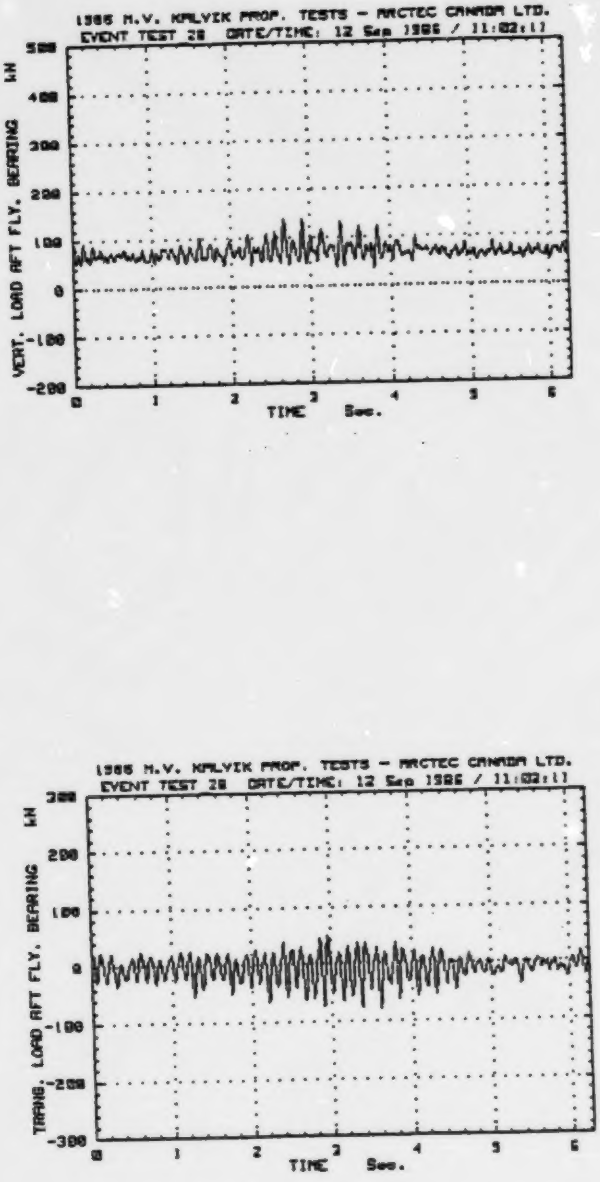


Figure 6.5.5c Response of Shaft Bearings
- Ice Milling

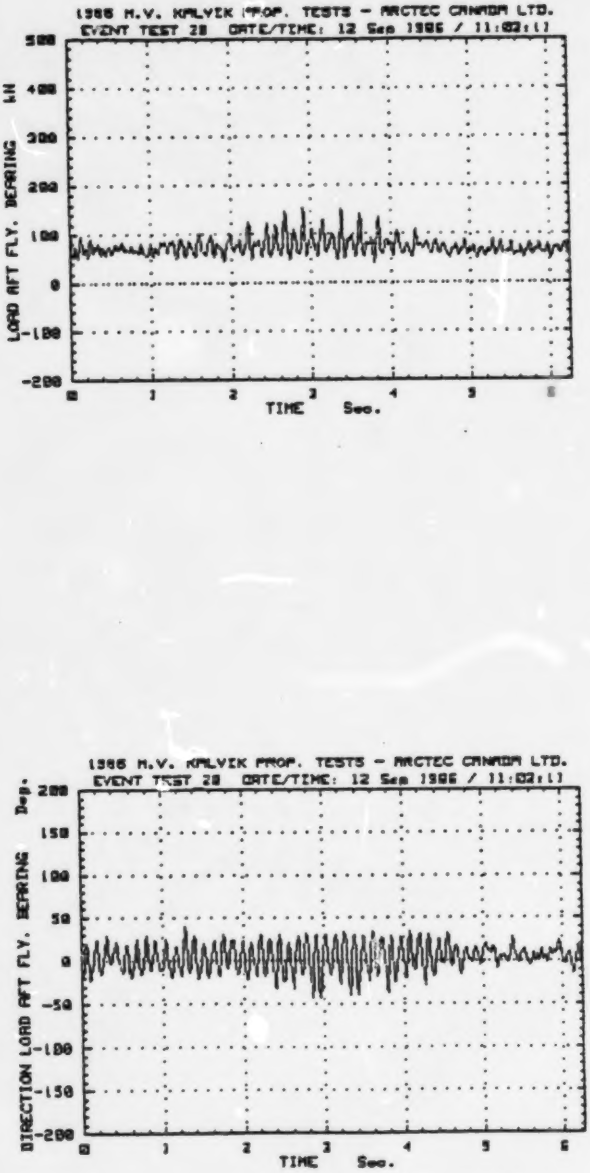


Figure 6.5.5d Response of Shaft Bearings - Ice Milling

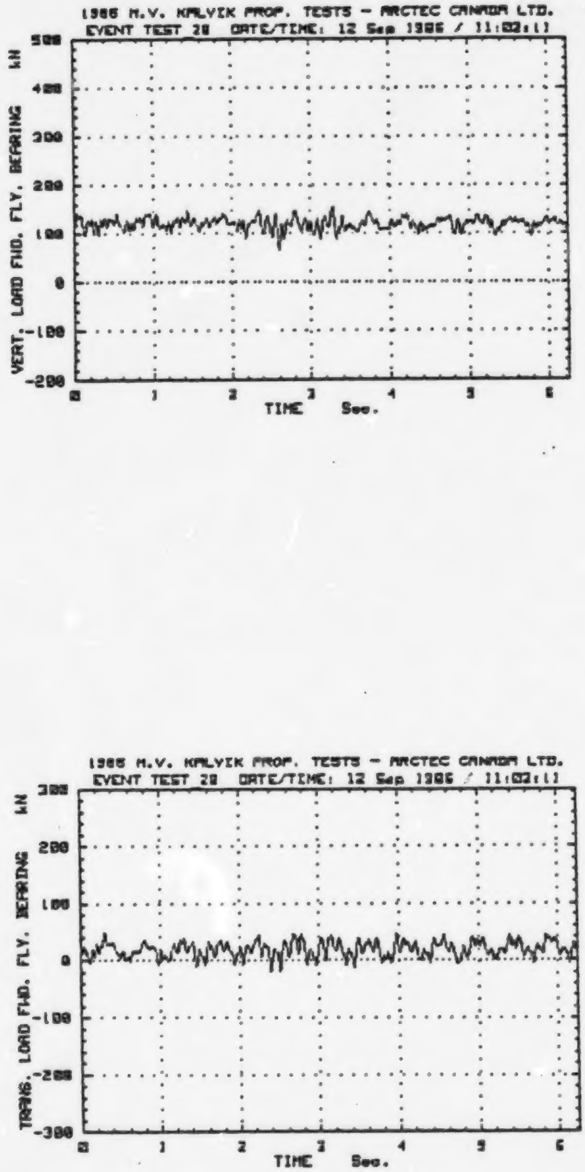


Figure 6.5.5e Response of Shaft Bearings - Ice Milling

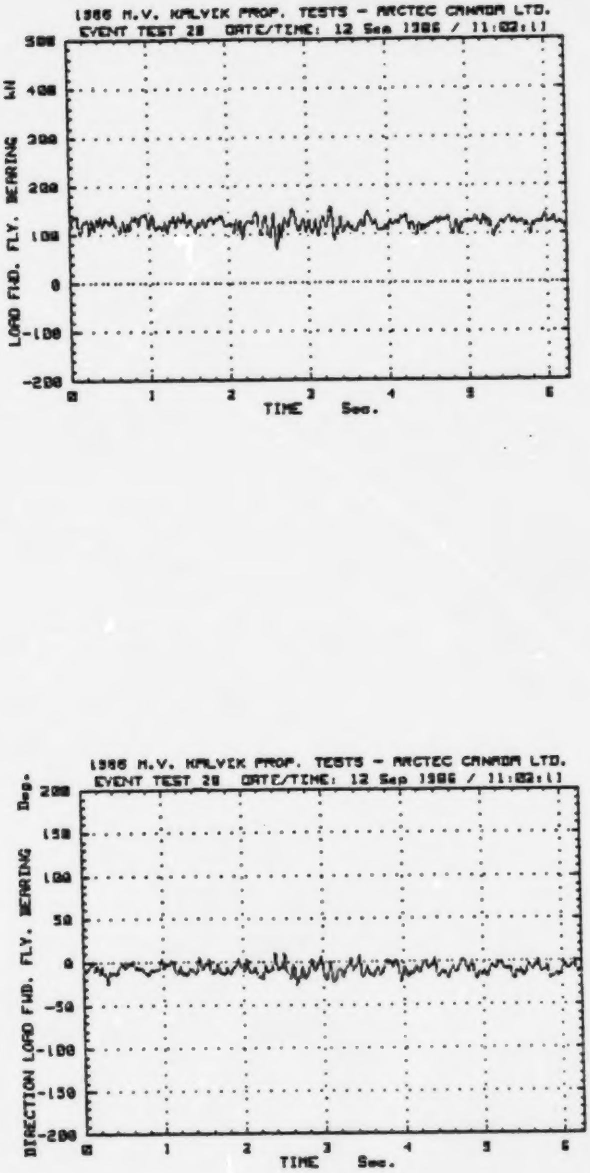


Figure 6.5.5f Response of Shaft Bearings - Ice Milling

6.6 Shafting Torque, Thrust, and Bending Response

Introduction / Summary

This section details the analysis of the starboard shafting torque, thrust and bending full scale data. The instrumentation included gauges to measure strains due to torque and thrust at one location, and bending at three locations, of the intermediate shafting as illustrated in Figure 6.6.1. General statistical analysis was done for all trial events, and detailed analysis of the time series plots was performed for selected extreme events.

There are two propulsion shafts, port and starboard, 3.5 m off the centreline on the M.V. Kalvik. The shaft line particulars are as follows:

Diameter of Intermediate Shaft	470. mm
Diameter of Tail Shaft	775. mm
Weight of Propeller Shaft	850. kN (85 tonnes)
Weight of Intermediate Shaft	170. kN (17 tonnes)
Weight of Flywheel	120. kN (12 tonnes)
Shaft BHP	11600. BHP
Shaft Speed	130. RPM
Shaft Torque at MCR	595. kNm
Maximum Over Torque	750. kNm for 2 seconds
Design Torque Limit	5114. kNm
Maximum Shaft Thrust at Bollard	990. kN (99 tonnes)

The following results were obtained from the analysis:

1. The maximum thrust variation measured was +1.4 MN to -2.4 MN with a rise time of 0.05 seconds and a frequency of approximately 8.7 Hz (blade rate). The vessel was going slow ahead and severe ice milling occurred.

2. The maximum torque variation measured was +500 kNm to +200 kNm with a rise time of 0.1 seconds and a frequency of approximately 4.0 Hz. The vessel was going slow ahead and severe ice milling occurred.

3. The shaft bending stress increased by approximately 20% from open water conditions during heavy ice milling.

4. The machinery conditions that caused the two highest propeller blade forces were the following:

   A. Heavy Milling (Test 28)
   - ahead propeller pitch was decreased from 11 to 2 degrees
   - rudder moved from 4 degrees port to 5 degrees starboard
   - low shaft torque (<500 kNm)
   - shaft thrust varied from 1 MN (100 tonnes) ahead to 2 MN (200 tonnes) astern.

   B. Ice Wedged between Rudder and Propeller (Test 09)
   - full ahead propeller pitch
   - rudder moved from 18 degrees to 35 degrees starboard
   - high shaft torque (820 kNm)
   - shaft thrust varied from 1 to 2.2 MN (100 to 220 tonnes) ahead

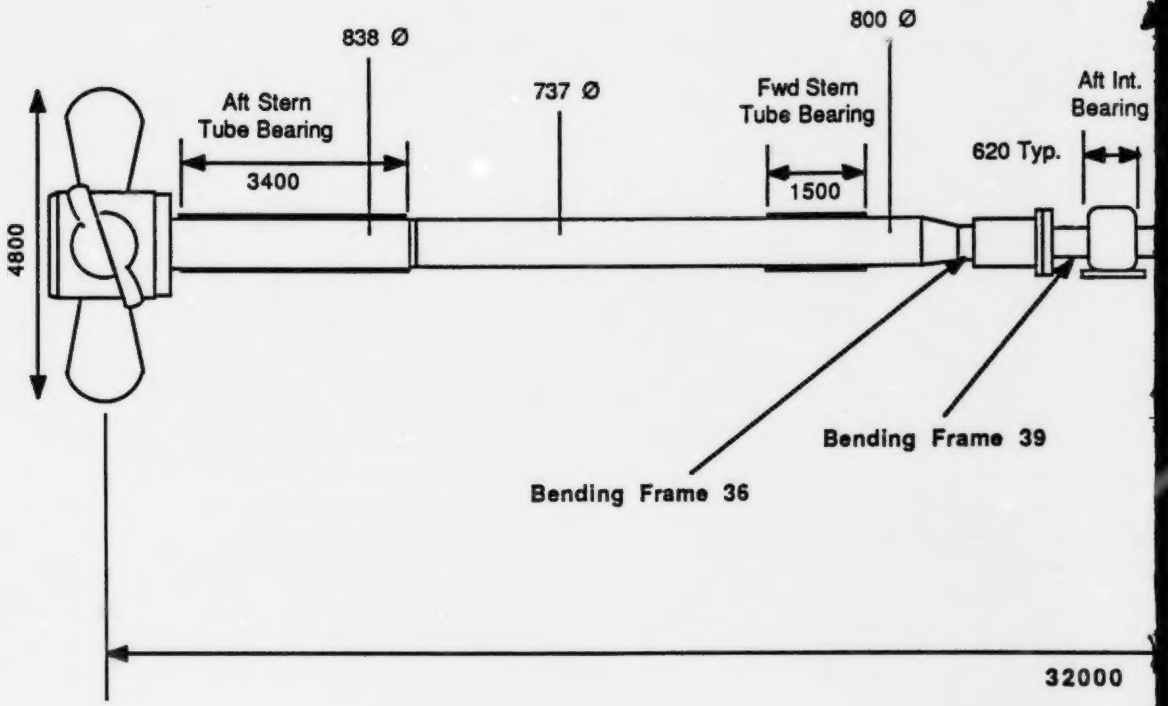
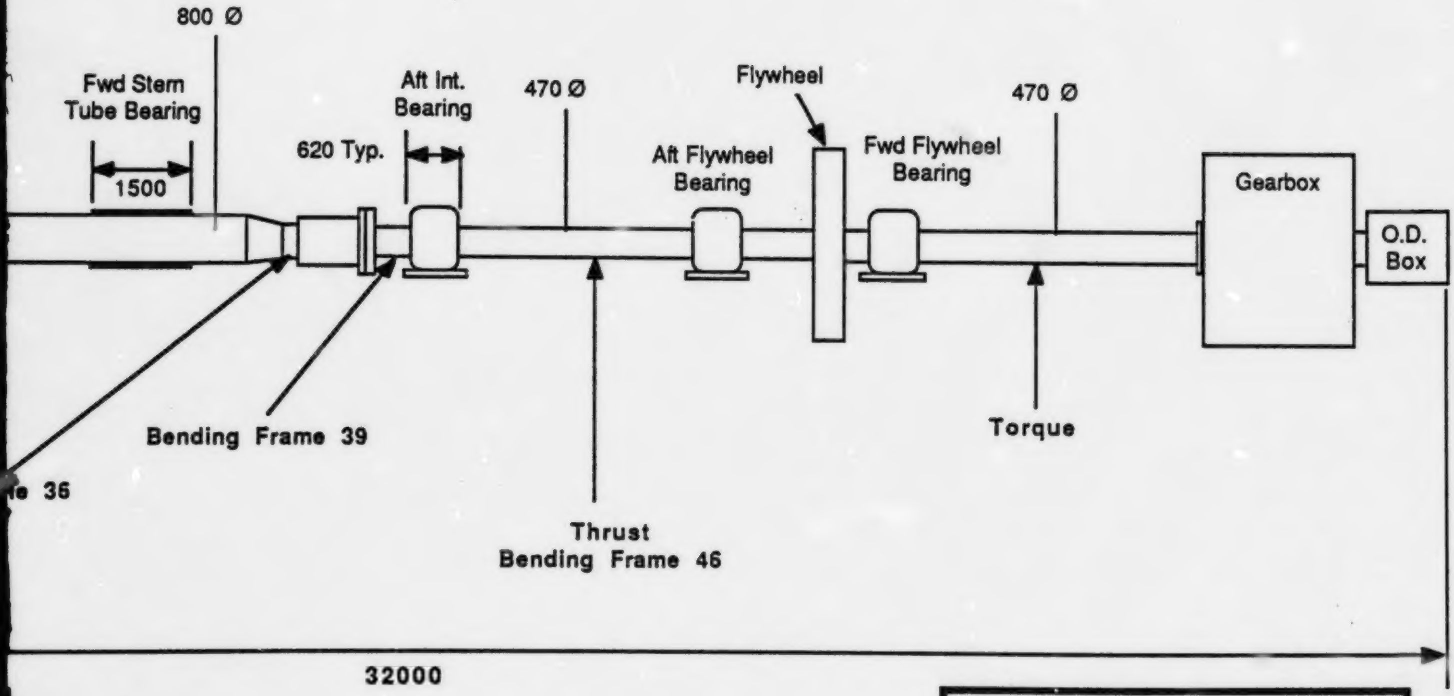


Figure 6.6.1 Starboard Shafting - Torqu



Scale 1:100
Dimensions in mm

Starboard Shafting - Torque / Thrust / Bending Measurements

5. Maximum shaft thrust measured: 2.15 MN (215 tonnes) ahead, 2.20 MN (220 tonnes) astern.

6. Maximum shaft torque measured: 820. kNm (82 tonne m)

7. Maximum shaft bending stress measured = 11. MPa (1600 psi)

Instrumentation and Measurement Procedure

Standard strain gauge configurations were used to measure stress due to thrust and bending. These signals were transmitted to a stationary FM antenna looped around the shaft. The shaft torque signal was sampled from the existing ASEA Torductor sensor forward of the flywheel. Figure 6.6.1 illustrates the location of the above sensors. The detailed calculations of the calibration factor and associated field notes are provided in Appendix D.

The signals were sampled at a rate of 500 readings per second and an event consisted of 6.25 seconds of data.

Data Base and Analysis Procedure

The data base for the statistical analysis included 29 events recorded during the performance trials with the CCGS John A. Macdonald [Ref. #307].

The statistical analysis included calculations of the mean, maximum and minimum values of the shaft torque, thrust and bending. A histogram of peak maximum and minimum values for each measurement was obtained.

Based on the statistical analysis, four extreme shaft bearing load events were selected and analysed:

- Ice Milling - 2 Events
- Ice Impact - 1 Event - Maximum Shaft Torque
- Ice Impact - 1 Event - Maximum Shaft Thrust

Time series data analysed included:

- Shaft Thrust
- Shaft Torque
- Shaft Bending - 3 locations
- Propeller Pitch
- Engine Fuel Rack Position
- RPM

The ship operation and ice conditions were also extracted from the data base. The detailed field notes and calibration calculations are provided in Appendix D.

Table 6.6.1 summarizes for each selected event the event label, the date and time, the activity category and the associated ice conditions.

Table 6.6.1 Selected Events for Intermediate Shafting Load Analysis

Event Label	Date	Time	Operation Category	Ice Conditions
TEST_09	05 Sept. 86	13:43:22	Turning to Stbd. - Icebreaking Full Ahead	2/10 old, 8/10 med. 1st yr ice, vast floes
TEST_18	07 Sept.86	09:38:18	Turning to Stbd. - Icebreaking 3/4 Ahead	2/10 old, 8/10 med. 1st yr ice, vast floes
TEST_24	09 Sept. 86	20:21:09	Turning to Stbd. - Icebreaking Full Ahead	4/10 old, 6/10 thick, 1st yr ice, vast floes
TEST_28	12 Sept. 86	11:02:11	Slow Ahead - Icebreaking	5/10 old, 4/10 med. 1st yr ice, vast floes

Results

Result Summary

Table 6.6.2 summarizes the results of the detailed analysis for the selected extreme events as well as the open water conditions. Comments relevant to the bearing response are also listed.

Table 6.6.2 Result Summary of Intermediate Shaft Loading Analysis

Event Label	Thrust Max. (MN)	Thrust Min. (MN)	Torque Max. (kNm)	Bending* Max. 1/2/3 (MPa)	RPM Max./Min.
Open Water	1.0	-	595.	3/10/5	130/128
Test_09	2.15	-0.2	820.	3/10/5	130/111
Test_18	1.5	-1.0	770.	3/10/5	135/120
Test_24	1.9	-0.7	820.	3/10/5	132/112
Test_28	1.4	-2.2	550.	5/12/7	132/123

Notes: 10 kN~ 1 Tonne, 1 MN~ 100 tonnes

* - 1/2/3 Shaft Bending Stress at Frames 36, 39 and 46 respectively.

Maximum Shaft Thrust - Ice Propeller Impact (Event Test_09)

The rudder was directed to the starboard from 18 degrees to 35 degrees (hard-over). Ice became wedged in between the rudder and the starboard propeller. The propeller milled the ice for approximately 1.8 seconds and then open water conditions resumed. The ice milling occurred between 2 and 3.8 seconds in the time history.

Time history plots for shaft thrust, and torque as well as pitch, fuel rack and RPM are illustrated in Figures 6.6.2 to 6.6.3. The shaft thrust oscillates between +2.15 MN and -0.2 MN during the ice propeller impact, with a rise time of 0.1 seconds. The shaft torque rises to 820 kNm for 0.6 seconds (over torque limit = 750 kNm for 2 seconds). The RPM drops from 128 (open water condition) to 112 at the peak of the ice propeller impact. The pitch remains between 20 and 19 degrees, and the fuel rack rises to 62 mm (full fuel rack) and drops down to 38 mm when the ice clears the propeller.

The shaft bending stress time histories at Frame 36, 39 and 46 are illustrated in Figure 6.6.4. There is no noticeable change in the shaft bending during the ice propeller interaction (2 - 3.8 seconds) from the open water conditions. This indicates that the increase in bearing reactions for this event (see Section 6.5) is mainly due to inertial loading and not shaft bending.

Heavy Ice Milling (Event Test_28)

The vessel was in ahead pitch of 10 degrees decreasing to 2 degrees. The rudder angle was varied from 4 degrees to port to 5 degrees starboard. The propeller milled the ice for approximately 5.5 seconds and then open water conditions resumed. The ice milling occurred between 0 and 5.5 seconds in the time history.

Time history plots for shaft thrust, and torque as well as pitch, fuel rack and RPM are illustrated in Figures 6.6.5 - 6.6.6. During this event the peak torque is less than the MCR of 595 kNm and the mean thrust is near zero. However, the shaft thrust oscillates between +1.4 MN and -2.4 MN during the ice-propeller impact, with a rise time of 0.05 seconds and a frequency of approximately 8.5 Hz (blade rate). The shaft torque varies +/- 150 kNm at a frequency of approximately 4 Hz with a peak magnitude of 560 kNm. The RPM rises from 123 to 132 as the ice clears the propeller. The pitch drops from 11 degrees to 2 degrees, and the fuel rack rises to 54 mm and drops down to 20 mm when the ice clears the propeller.

The shaft bending stress time histories at Frame 36, 39 and 46 are illustrated in Figure 6.6.7. There is no noticeable change in the shaft bending at Frames 36 and Frames 46 during the ice propeller interaction compared with the open water conditions. The shaft bending at Frame 39 varies approximately 20% from the open water condition.

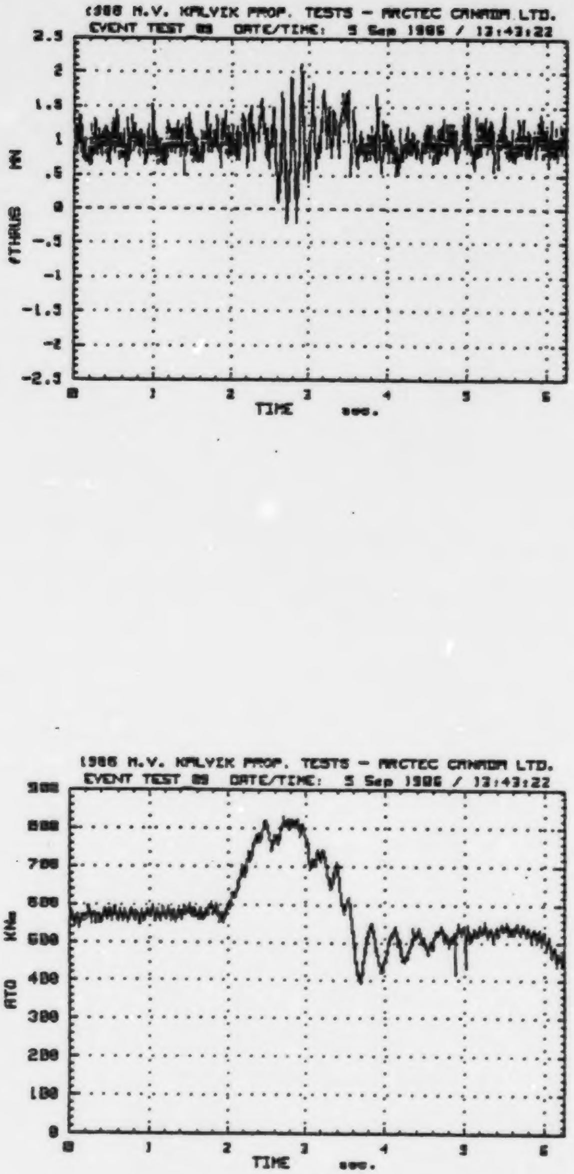


Figure 6.6.2 Shaft Torque and Thrust - Ice Propeller Impact

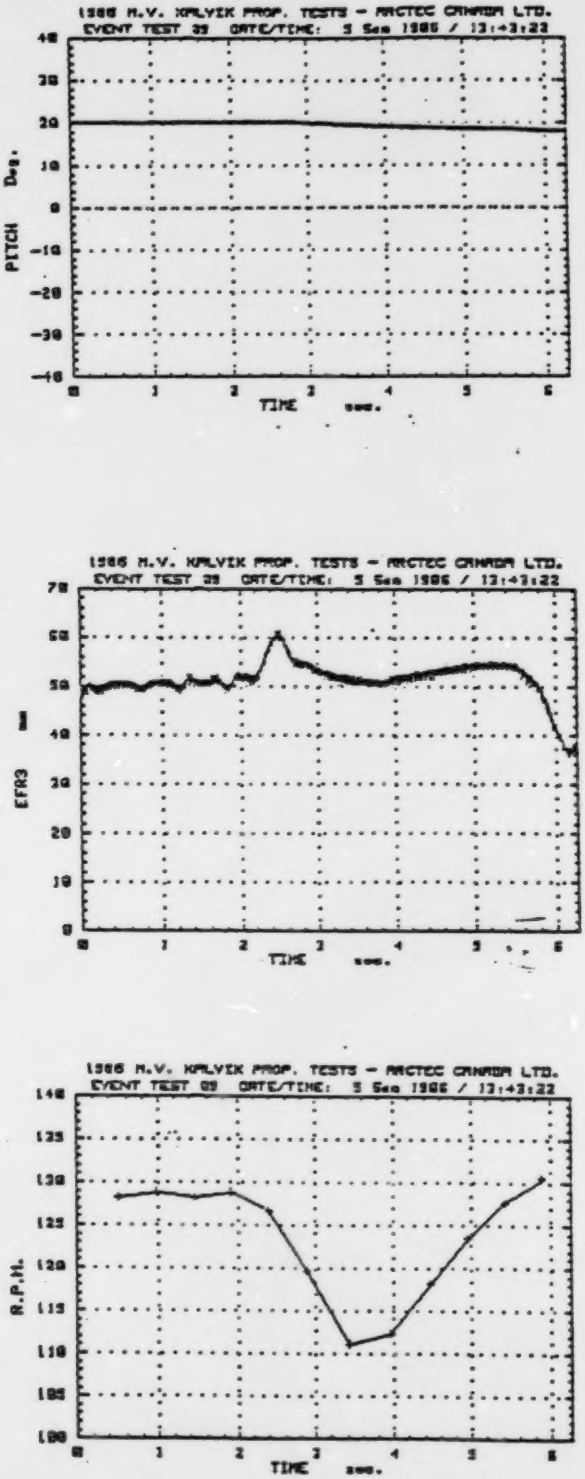


Figure 6.6.3 Pitch, Fuel Rack, R.P.M.
- Ice Propeller Impact

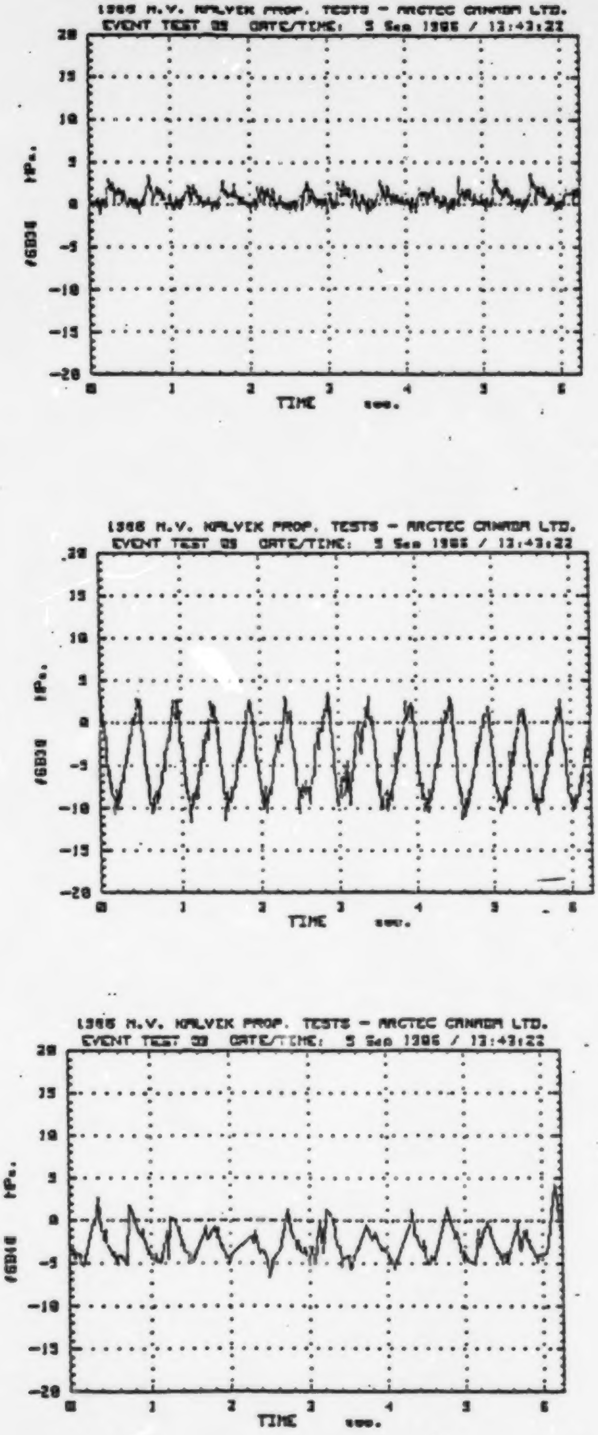


Figure 6.6.4 Shaft Bending Response
- Ice Propeller Impact

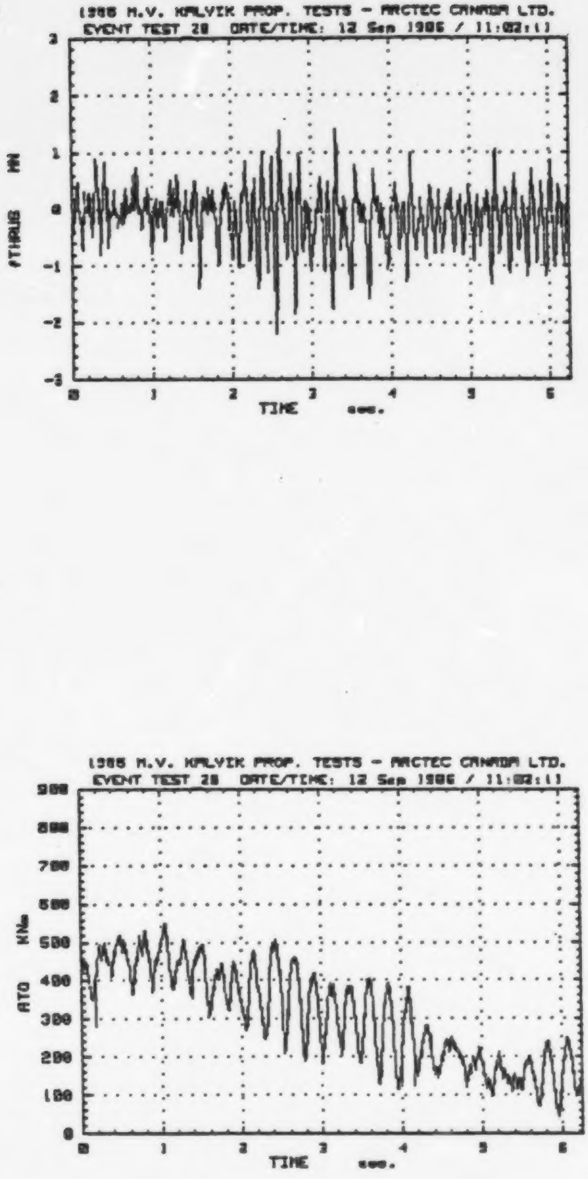


Figure 6.6.5 Shaft Torque and Thrust - Ice Milling

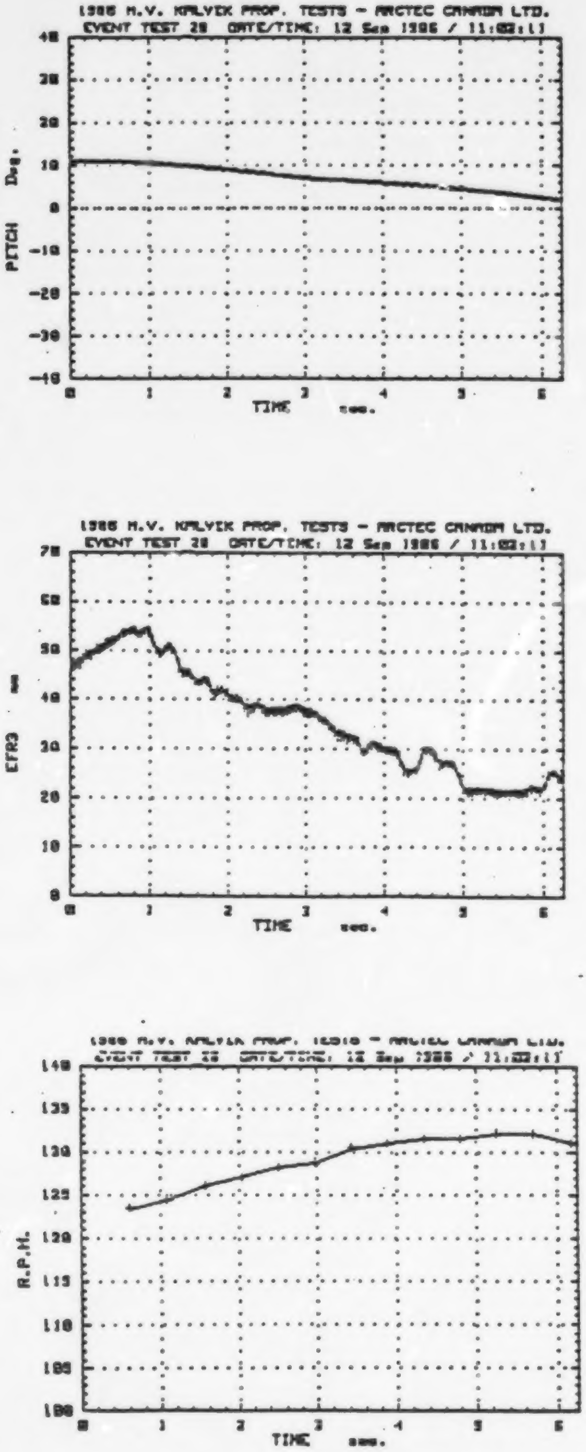


Figure 6.6. 6 Pitch, Fuel Rack, R.P.M.
- Ice Milling

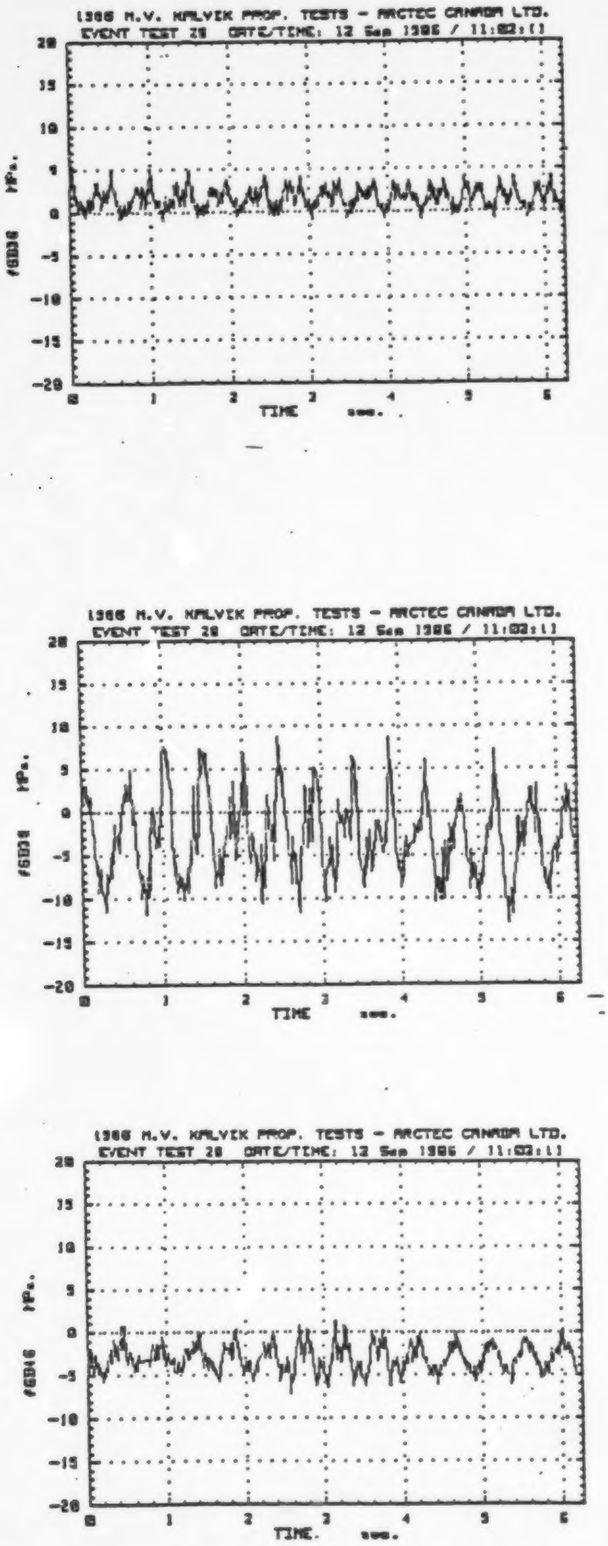


Figure 6.6.7 Shaft Bending Response - Ice Milling

6.7 Shaft Transverse and Vertical Movement

Introduction / Summary

This section details the data analysis of the starboard shaft motions as measured immediately forward of the stern tube seal which is 770 mm forward of the forward stern tube bearing. The instrumentation included proximity probes which measure the displacement of the shaft in the axis of the probe. The velocity and acceleration of the shaft can be calculated by differentiation of the measured displacement time history wave form.

General statistical analysis was done for all trial events, and detailed analysis of the time series plots was performed for selected extreme events.

There are two propulsion shafts, port and starboard, 3.5 m off the centerline, on the M.V. Kalvik. The location of the displacement measuring probes are shown in Figure 6.7.1 and Figure 6.7.2. The particulars relating to the analysis of the shaft movement are as follows:

Diameter of Intermediate Shaft	470. mm
Weight of Propeller Shaft	850. kN (85 tonnes)
Diametral Clearances	
- Forward Stern Tube Bearing	2.4 mm (Transverse) 1.8 mm (Vertical)
- Aft Stern Tube Bearing	2.0 mm (Transverse) 1.5 mm (Vertical)
- Stern Tube Seal Clearance	2.0 mm (Average)

The stern tube bearings are salt water lubricated with a seal at the forward end of the forward stern tube bearing. The aft end or the stern tube is open to the sea.

The following results were obtained from the analysis:

1. Extreme shaft movements occur in an ice milling condition with low propeller pitch angles (low torque) and when ice is wedged between the centerline of the vessel and the propeller.

2. Shaft accelerations of up to -5.5 m/sec^2 (0.56 g's) in the vertical direction and -6.5 m/sec^2 (-0.66 g's) in the transverse direction (to starboard) were measured at the stern tube seal during ice milling.

3. Shaft displacements as high as 2.3 mm (0.091 inches) in the vertical direction and 1.9 mm (0.075 inches) in the transverse direction (to starboard) were measured at the stern tube seal during ice milling.

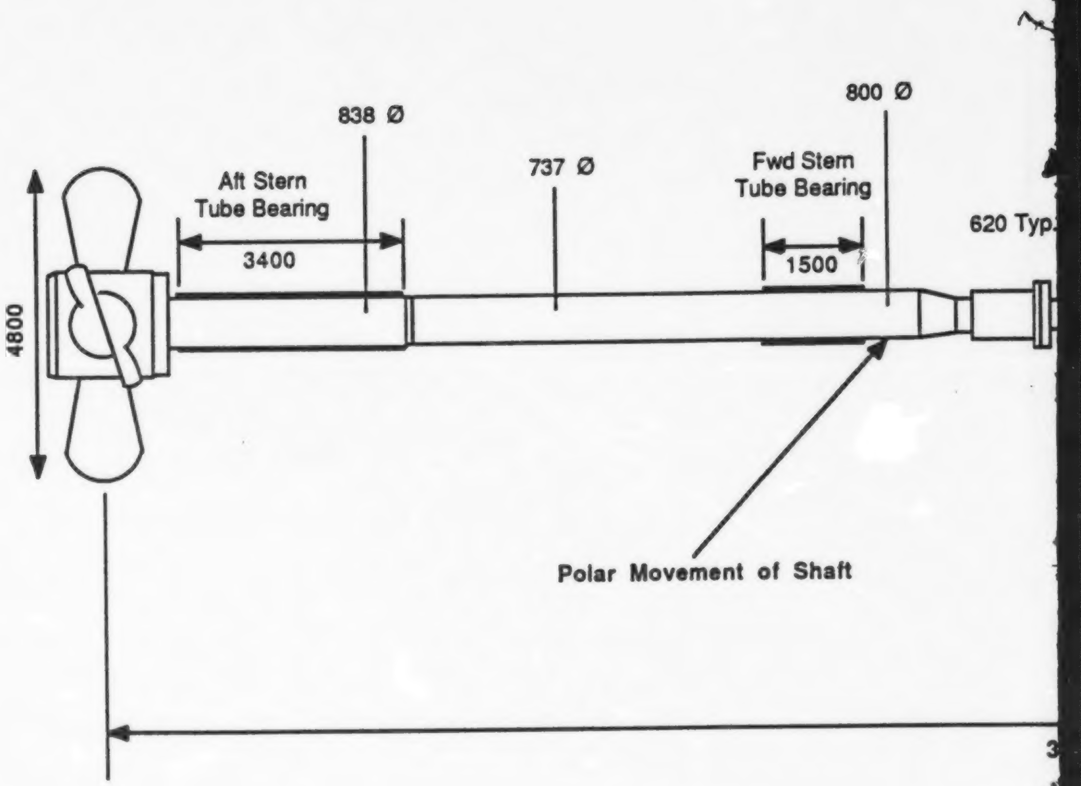
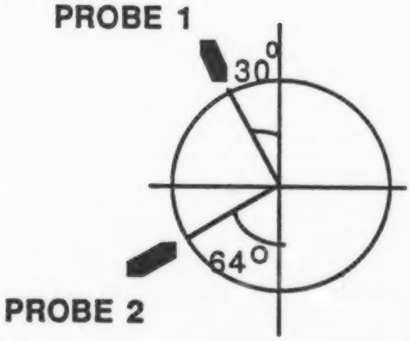
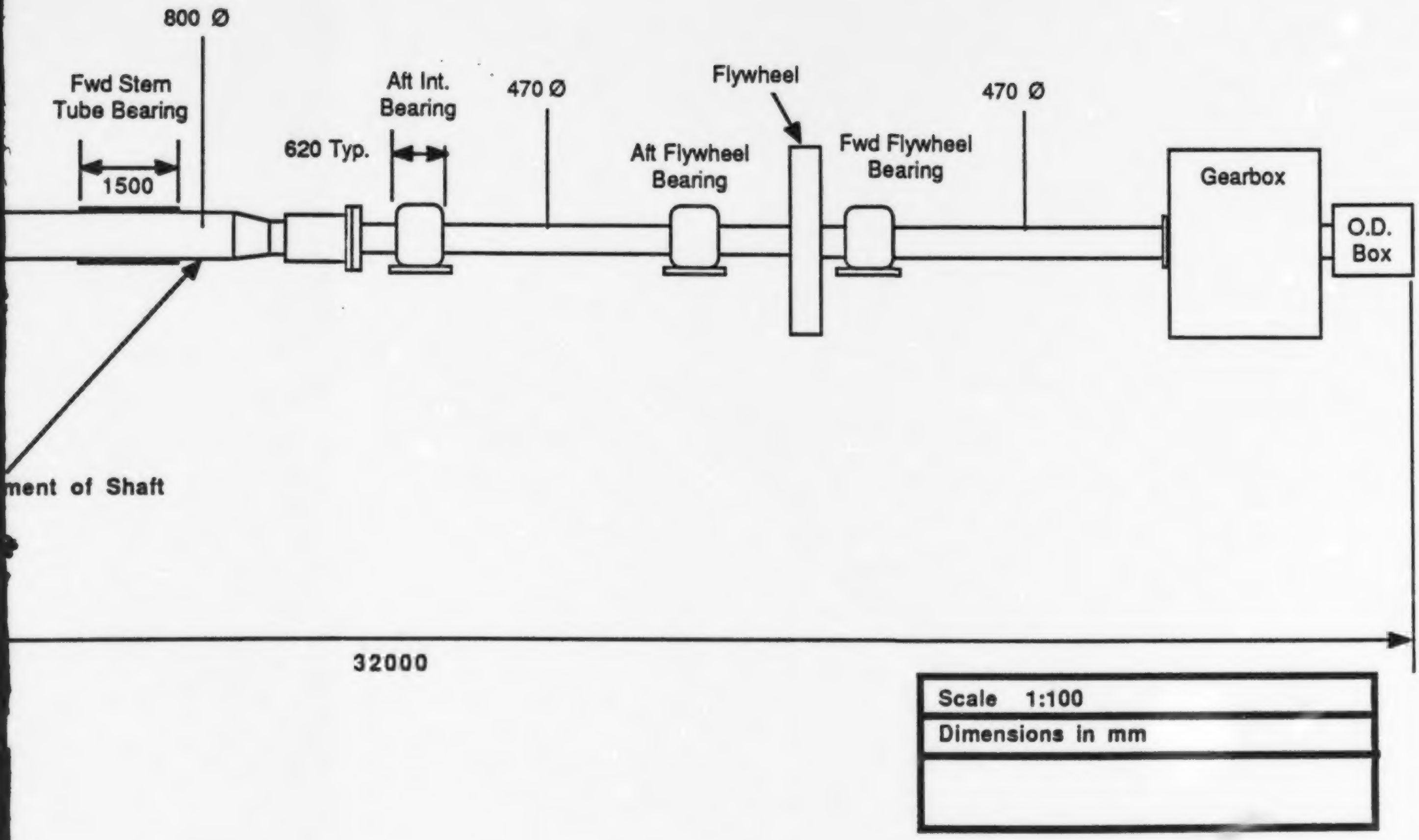


Figure 6.7.1 Starboard Shaft



Looking Forward at Stern Tube Seal

FIGURE 6.7.2 Location of Proximity Probes - Looking Forward



.7.1 Starboard Shafting - Shaft Movement Measurements

rward

Instrumentation and Measurement Procedure

Standard proximity probes were used to measure the movement of the shaft in the axis of the probe. Two probes were mounted on the forward stern tube seal 86 degrees apart from each other as shown in Figure 6.7.2. The displacement of the shaft was measured in two directions (by each probe). These two distance measurements were resolved into a coordinate system consisting of a vertical and transverse (port to starboard) axis. The detailed calculations of the calibration factor and associated field notes are provided in Appendix D.

The signals were sampled at a rate of 500 readings per second and an event consisted of 6.25 seconds of data.

Data Base and Analysis Procedure

The data base for the statistical analysis included 72 ice/propeller interaction events.

The statistical analysis included calculations of the mean, maximum and minimum values of the shaft movement as measured by each probe.

Based on the statistical analysis four extreme shaft bearing load events were selected and analysed:

- Ice Milling - 1 Event - Ice Between Propeller and Rudder
- Ice Impact - 1 Event - Maximum Shaft Torque
- Ice Impact - 1 Event - Maximum Shaft Thrust

Time series data analysed included:

- Polar plots of Shaft displacement
- Vertical Shaft Displacement / Velocity / Acceleration
- Transverse Shaft Displacement / Velocity / Acceleration

The ship operation and ice conditions were also extracted from the data base.

Table 6.7.1 summarizes for each selected event the event label, the date and time, the activity category and the associated ice conditions.

Table 6.7.1 Selected Events for Shaft Movement Analysis

Event Label	Date	Time	Operation Category	Ice Conditions
TEST_09	05 Sept. 86	13:43:22	Turning to Stbd. - Icebreaking Full Ahead	2/10 old, 8/10 med. 1st yr ice, vast floes
TEST_18	07 Sept. 86	09:38:18	Turning to Stbd. - Icebreaking 3/4 Ahead	2/10 old, 8/10 med. 1st yr ice, vast floes
TEST_28	12 Sept. 86	11:02:11	Slow Ahead - Icebreaking	5/10 old, 4/10 med. 1st yr ice, vast floes

Results

Result Summary

Table 6.7.2 summarizes the results of the detailed analysis for the selected extreme events as well as the open water conditions. Comments relevant to the shaft movement are also listed.

Table 6.7.2 Result Summary of Shaft Movement Analysis

Event Label	Maximum Values						Comments
	Displacements) (mm)		Velocities (mm/sec.)		Accelerations (m/sec^2)		
	Vert.	Trans.	Vert.	Trans.	Vert.	Trans.	
Open Water	0.15	0.15	2.	2.	1.0	1.0	Negligible Shaft Movement
Test_09	1.1	1.5	20.	60.	1.5	-3.5	Maximum Thrust Event
Test_18	2.3	1.5	55.	70.	-5.5	-5.0	Ice Milling
Test_28	2.1	1.9	-62.	90.	-4.5	-6.5	Heavy Ice Milling

Notes: 1 mm ~ .039 inches
1 m/sec.^{2} ~ 0.1 g acceleration
Positive Vertical Movement - Upwards
Positive Transverse Movement - To Starboard

Maximum Shaft Thrust - Ice Propeller Impact (Event Test_09)

The rudder was directed to the starboard from 18 degrees to 35 degrees (hard-over). Ice became wedged in between the rudder and the starboard propeller. The propeller milled the ice for approximately 1.8 seconds and then open water conditions resumed. The ice milling occurred between 2 and 3.8 seconds in the time history.

A polar plot of the shaft displacement during ice-propeller impact and open water are illustrated in Figure 6.7.3 and Figure 6.7.4 respectively. During the ice impact the shaft movement is predominantly in the starboard direction and compresses the bearing approximately 0.65 mm.

The corresponding vertical and transverse shaft displacement, velocity and acceleration time histories are shown in Figures 6.7.5 - 6.7.9. The shaft vertical and transverse displacement oscillates at the blade rate of 8-9 Hz from +1.05 to 0.0 mm and from+1.5 to -0.6 mm respectively with a rise time of 0.1 seconds. The shaft moves less than 0.2 mm during the open water part of the event.

The vertical and transverse accelerations oscillate at the blade rate of 8-9 Hz from 3.5 m/sec^2 to -4.5 m/sec^2 and 4.5 to -6.5 m/sec^2 with a rise time of .04 seconds.

Heavy Ice Milling (Event Test_28)

The vessel was in ahead pitch of 10 degrees decreasing to 2 degrees. The rudder angle was varied from 4 degrees to port to 5 degrees starboard. The propeller milled the ice for approximately 5.5 seconds and then open water conditions resumed. The ice milling occurred between 0 and 5.5 seconds in the time history.

A polar plot of the shaft displacement during ice milling and relatively open water are illustrated in Figure 6.7.8 and Figure 6.7.9 respectively. During the ice impact the shaft movement is predominantly in the starboard direction and compresses the bearing approximately 1.0 mm.

The corresponding vertical and transverse shaft displacement, velocity and acceleration time histories are shown in Figures 6.7.10 to 6.7.12. Figure's 6.7.13 to 6.7.15 illustrates the shaft motion during the maximum movement (2.5-3.5 seconds). The shaft vertical and transverse displacement oscillates at the blade rate of 8-9 Hz from +2.1 to 0.0 mm and from+1.9 to -1.1 mm respectively with a rise time of 0.1 seconds. The shaft moves less than 0.2 mm during the open water part of the event.

The vertical and transverse accelerations oscillate at the blade rate of 8-9 Hz from 1.8 m/sec^2 to -1.8 m/sec^2 and 1.8 to -3.8 m/sec^2 with a rise time of .04 seconds.

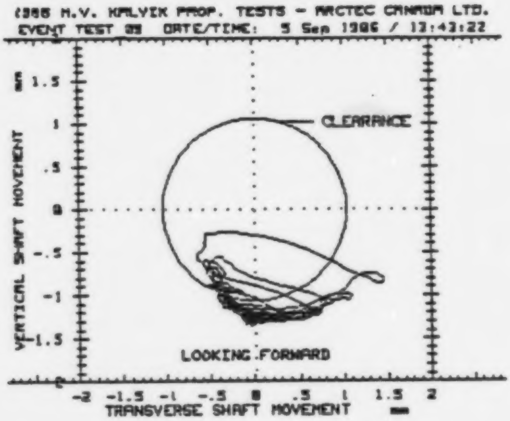


Figure 6.7.3 Shaft Movement Ice - Propeller Impact

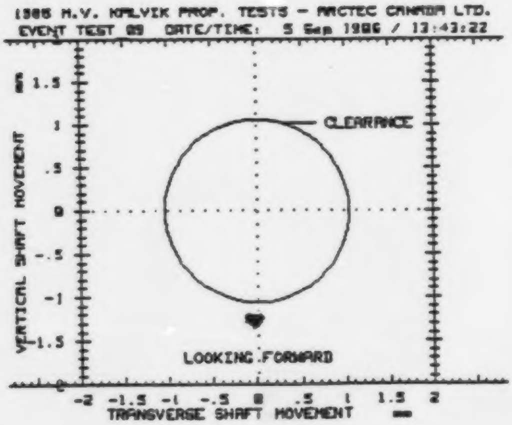
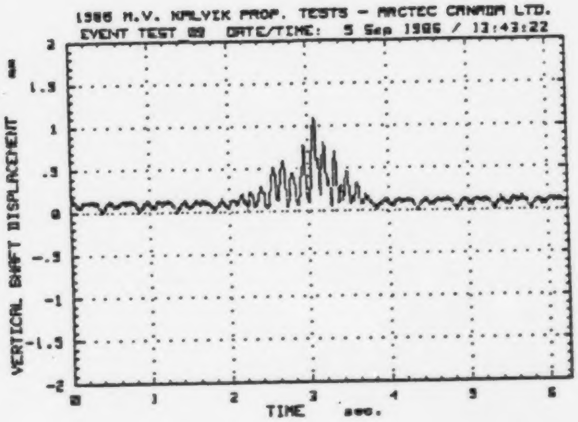


Figure 6.7.4 Shaft Movement Open Water



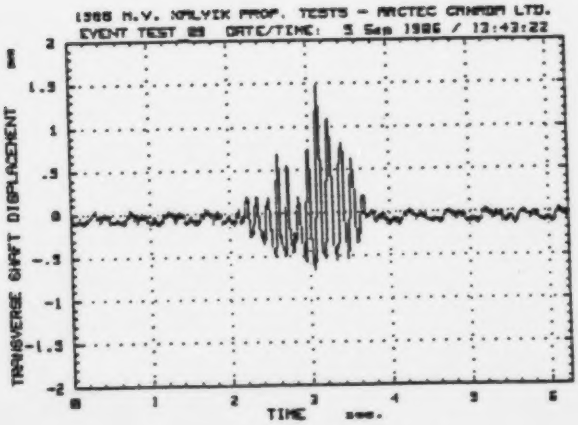
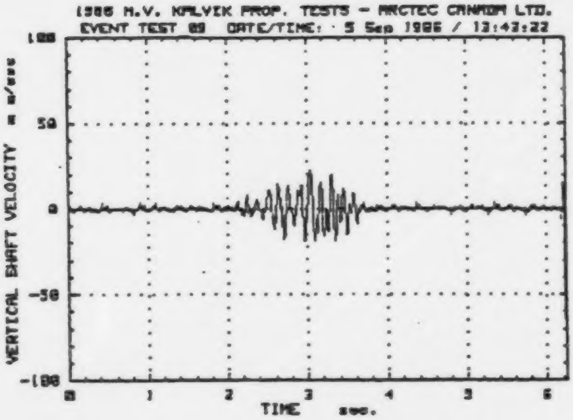


Figure 6.7.5 Shaft Displacement - Ice Propeller Impact



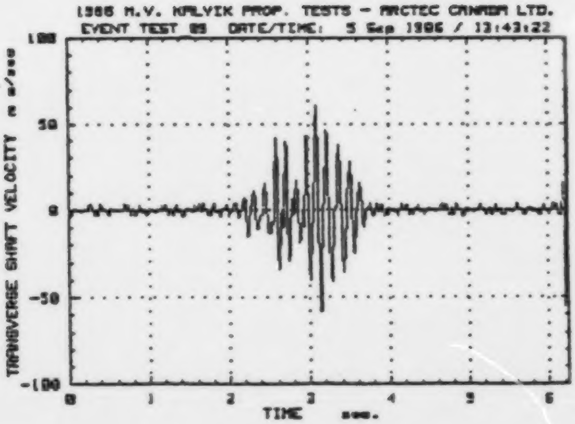


Figure 6.7.6 Shaft Velocity Ice - Ice Propeller Impact

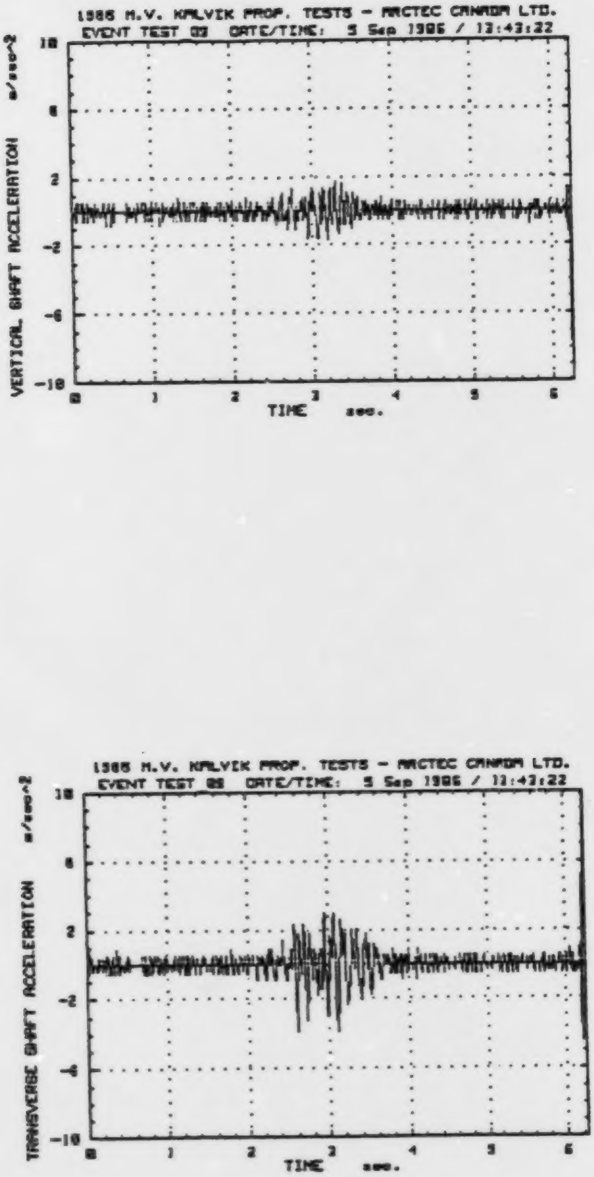


Figure 6.7.7 Shaft Acceleration Ice - Ice Propeller Impact

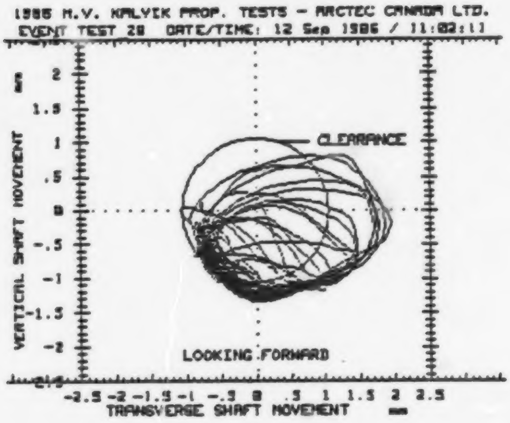


Figure 6.7. 8 Shaft Movement Ice Milling

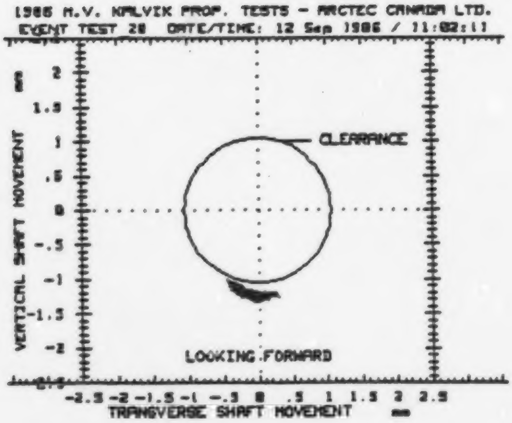


Figure 6.7. 9 Shaft Movement Open Water

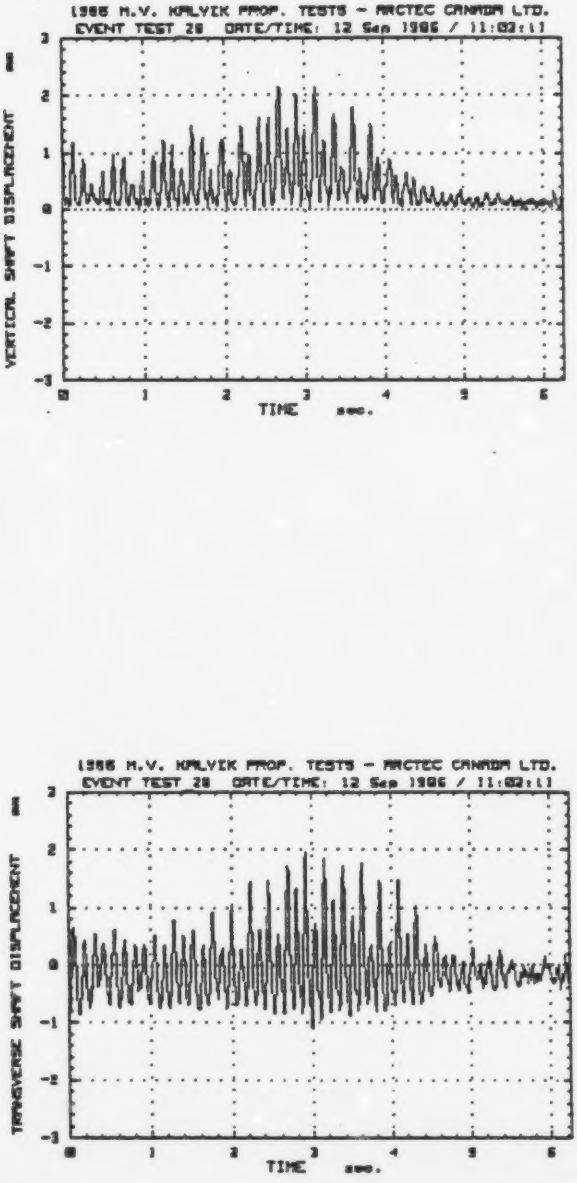
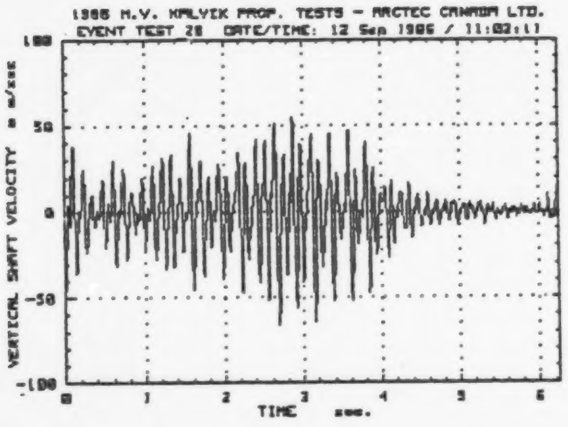


Figure 6.7.10 Shaft Displacement Ice Milling



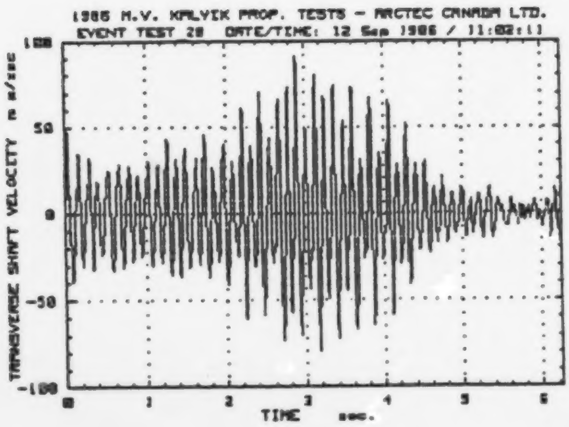


Figure 6.7.11 Shaft Velocity Ice Milling

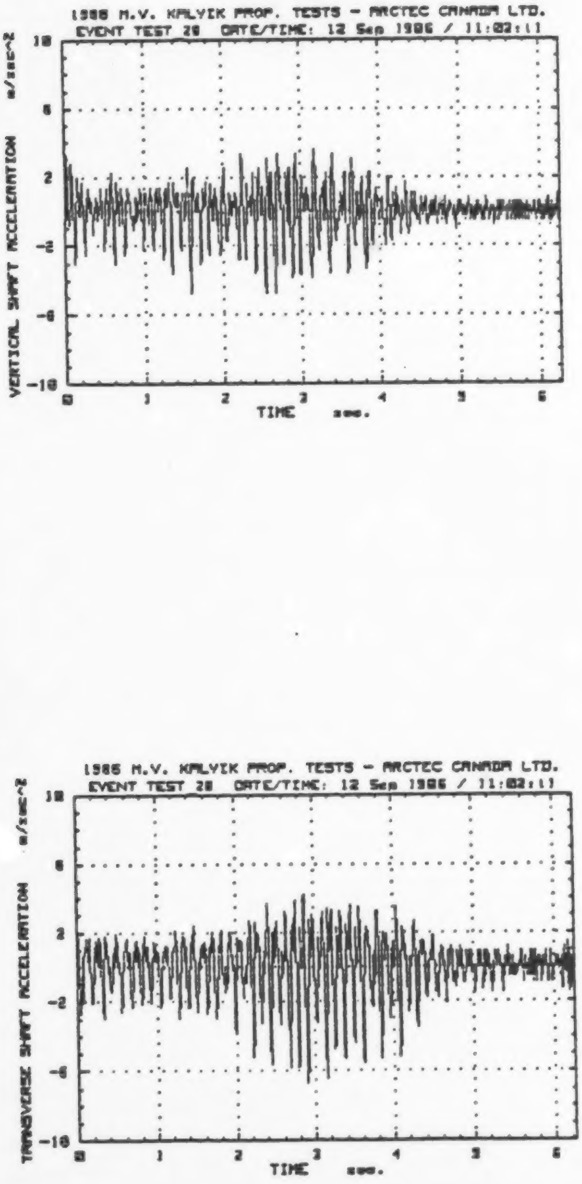


Figure 6.7.12 Shaft Acceleration Ice Milling

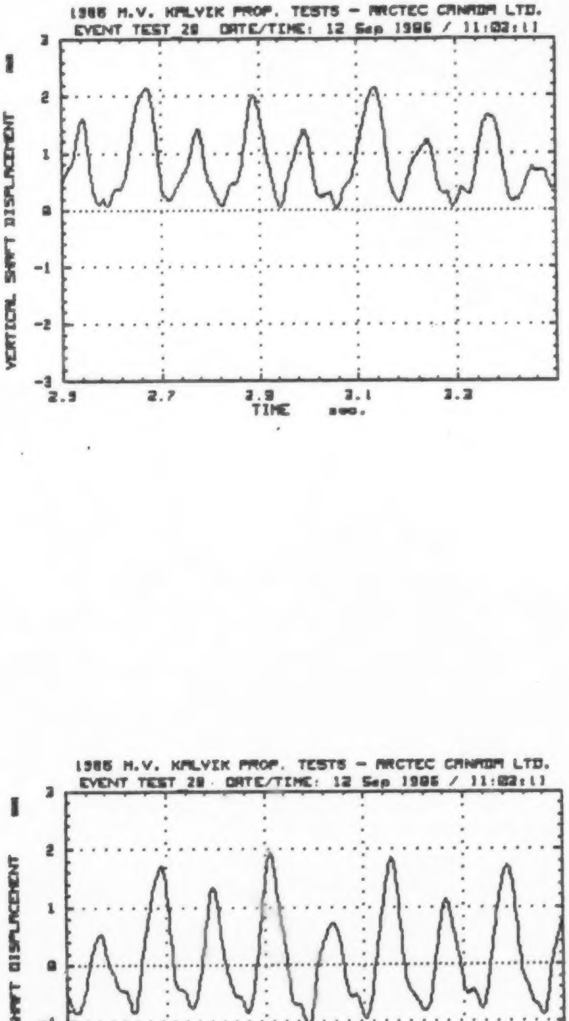


Figure 6.7.13 Shaft Displacement Ice Milling
2.5 - 3.5 seconds

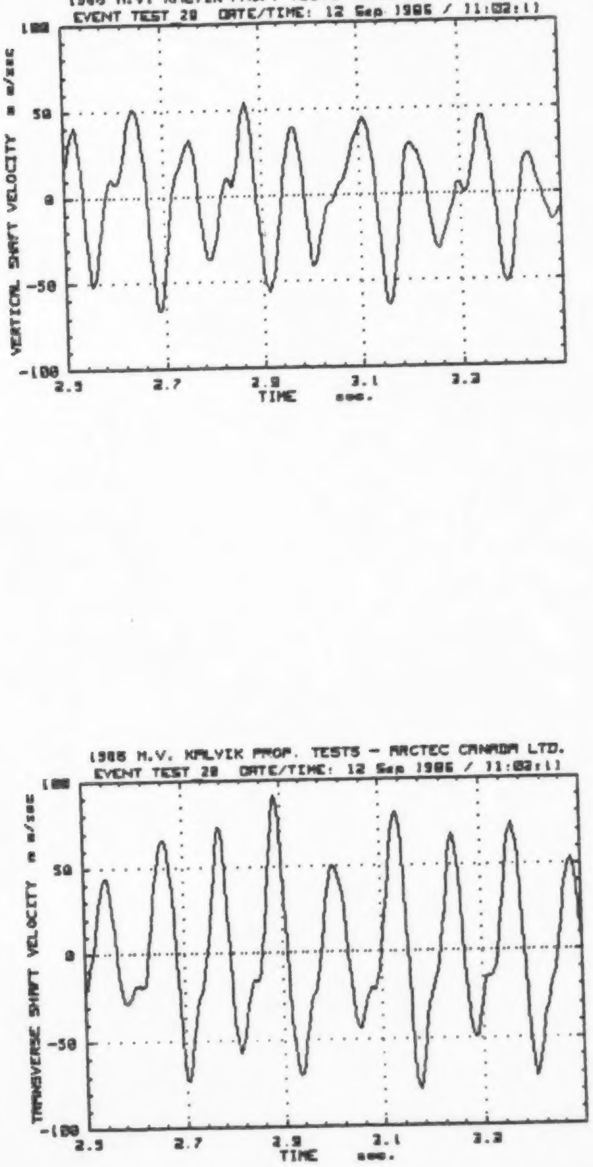


Figure 6.7.14 Shaft Velocity Ice Milling
2.5 - 3.5 seconds

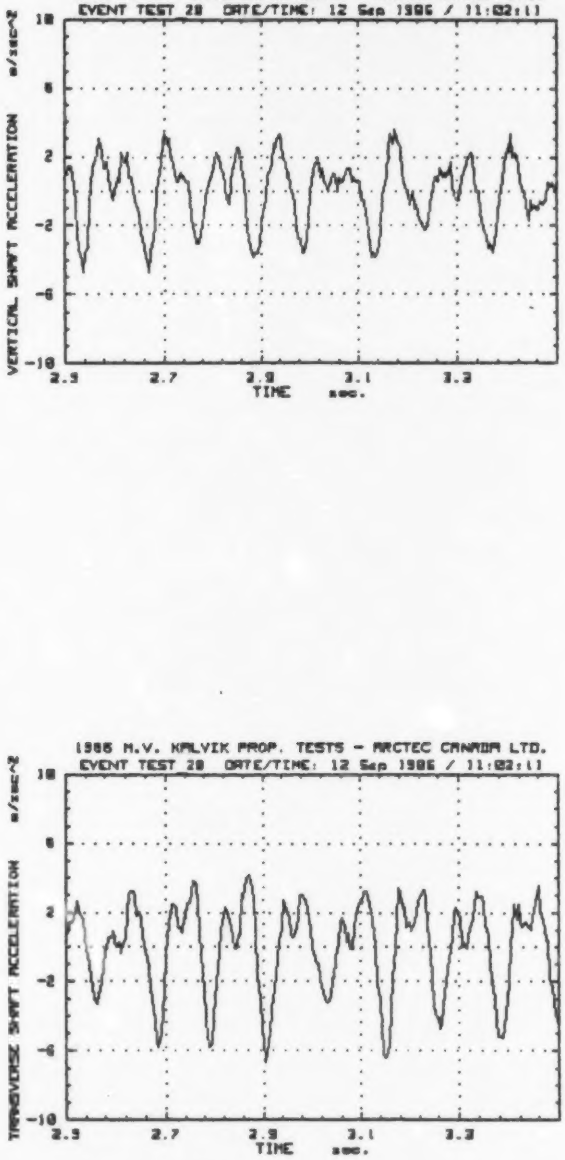


Figure 6.7. 15 Shaft Acceleration Ice Milling 2.5 - 3.5 seconds

6.8 Gear Case Deformations

Introduction / Summary

Strain gauges measuring the deformation of the gear case were installed as illustrated in Figure 6.8.1. The output from these sensors was used to assess the effect of ice-propeller interaction on the gear box. This section details the analysis of these measurements.

There is one gear box for each of the two propeller shafts on the M.V. Kalvik. The particulars of the gear boxes are as follows:

- Twin Input Single Output	
- Gear Ratio	4.625:1
- Total Weight	33,0000. kg
- Gear Wheel Mass	5660. kg
- Power Take Off	1000. kW @ 1200 RPM
- Built in Thrust Pad	

The following significant results were obtained from the analysis:

1. The maximum strain difference between the gear case walls was 32 μstrain. This corresponds to a maximum misalignment of 0.0022 degrees which is insignificant.

2. The maximum measured stresses on the gear case due to the loads transmitted through the shaftline are insignificant.

3. The aft gear case responds in a quasi-static fashion for torque excitation and in a vibratory fashion to thrust excitation.

Instrumentation

Two strain gauges were positioned on the gear case as shown in Figure 6.8.1. The locations were so chosen as to monitor the differences in strains in the forward and aft wells of the gear case which can be considered as an indication of the change of the alignment of the gears or deformation of the gear case.

Data Base and Analysis Procedure

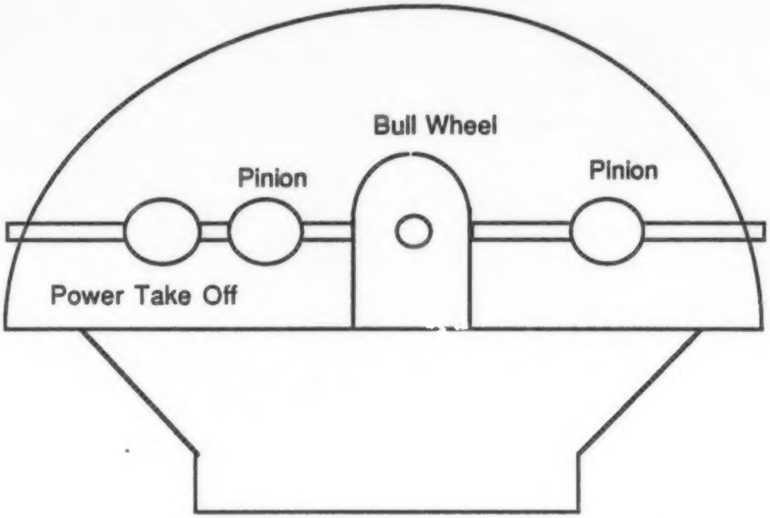
Two extreme events were analysed:

1. Minimum Thrust (Test 28)
2. Maximum Thrust (Test 09)

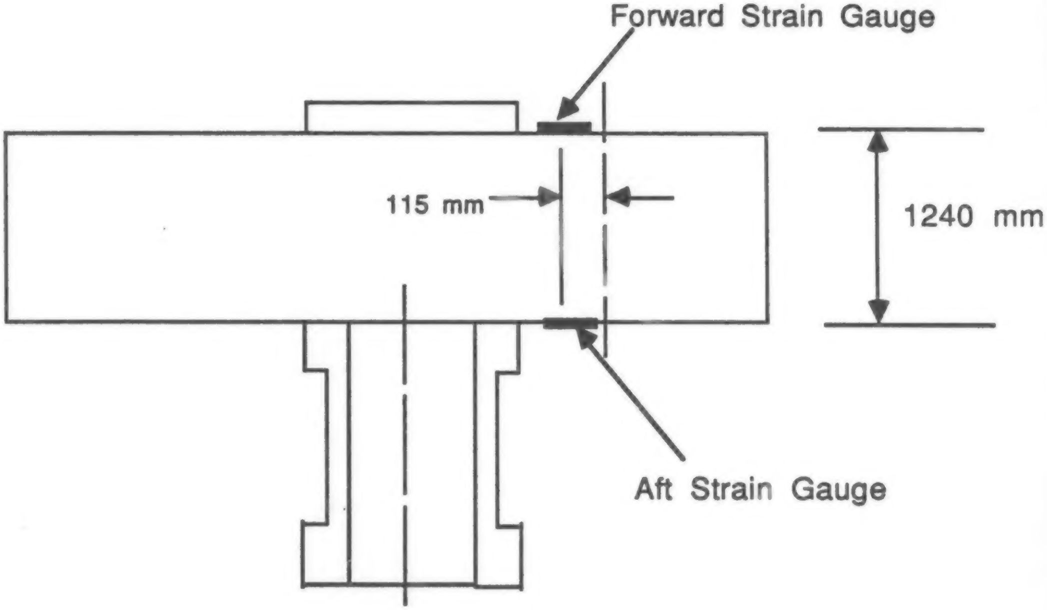
The stress of the gear case = (measured strain)(elastic modulus).

The misalignment calculations can be performed under the assumption that the strain is uniform over the distance between bull wheel and pinion (1.5 m).

Total deformation = (Strain Difference)(Distance between Gauges)
Angular misalignment = Total deformation / 1.5 m
Distance between gauges = 1.2 m (see Figure 6.8.1)



Gear Case Looking Forward



Gear Case Plan View

Figure 6.8.1 Gear Case Instrumentation

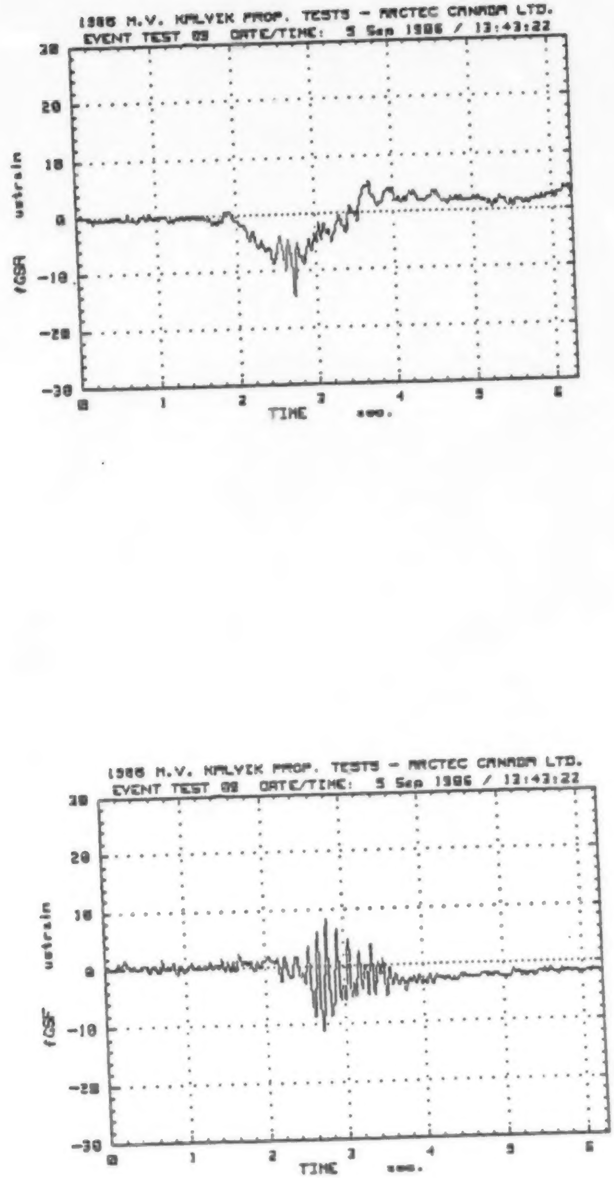


Figure 6.8.2 Gear Case Strains Ice - Propeller Impact

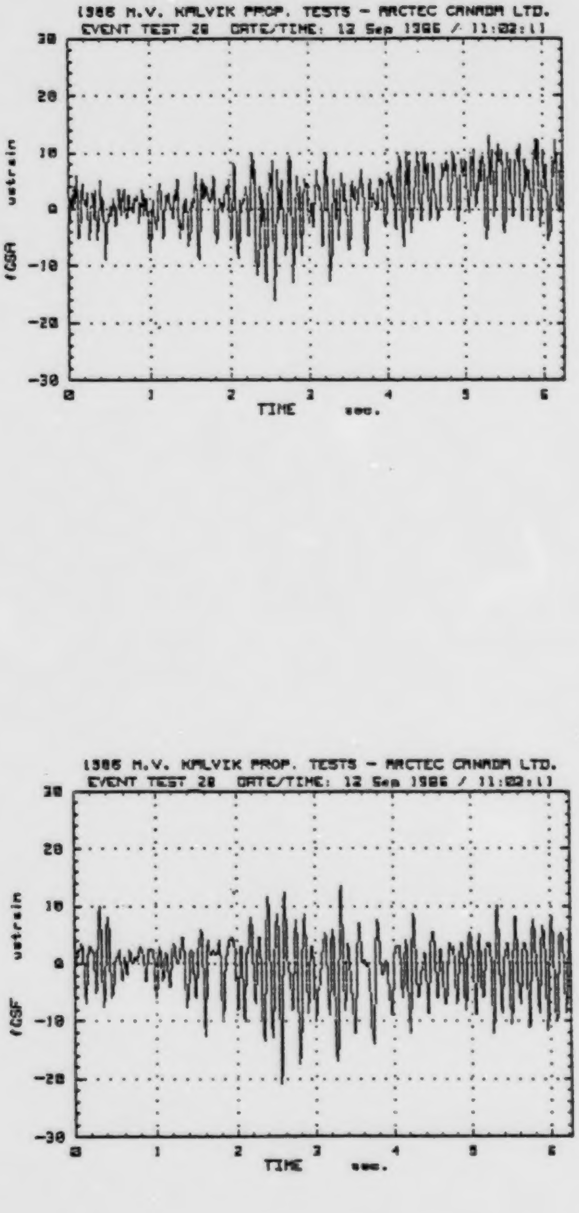


Figure 6.8.3 Gear Case Strains Ice Milling

Results

Plots of the gear case deformation for the maximum and minimum thrust events are illustrated in Figure 6.8.2 and Figure 6.8.3 respectively. The corresponding shaft thrust and torque time histories are illustrated in Section 6.6 (Figure 6.6.6 and Figure 6.6.9).

Analysis of these figures yield the following:

1. The maximum strain difference between the gear case walls was 32 µstrain. This corresponds to a maximum misalignment of 0.0022 degrees which is insignificant.
2. For the maximum torque event the gear case strain increase corresponds with the increase in torque.
3. For the maximum thrust event the gear case strain increase corresponds with the increase in thrust and not the torque.
4. The forward gear case deformation responds in a vibratory fashion oscillating about the mean value for both events.
5. The aft gear case deformation responds in a quasi-static fashion for torque excitation and in a vibratory fashion to thrust excitation.
6. The maximum strain recorded was 22 µstrain located on forward gear case wall.
7. The maximum strain recorded on the aft gear case wall was 16 µstrain.
8. The maximum stress calculated was 4.62 MPa. (670 psi). This is a small fraction of the yield of the gear case material (240 MPa) (34,800 psi).
9. In both events, the maximum strains and stresses are compressive.
10. Gear case vibrates with the frequency corresponding to the blade pass frequency of 8.67 Hz.

6.9 Effect of Vibrations on Shaft Line Supports

Introduction / Summary

Accelerometers orientated in the vertical direction were mounted in the port and starboard shaft tunnels immediately forward of the stern tube seal. One vertical accelerometer was mounted at the forward end of the vessel in the bow area (Figure 6.9.1). The output of these sensors was used to assess the severity and distribution of local vibrations and their relationship to bearing reactions.

The following significant results were obtained from the analysis:

1. Ice milling induces vibrations with structural vertical accelerations as high as 12 m/sec^2 (1.2 g's) near the stern tube seal.
2. The structural vibrations are limited to the local area around the stern tube seal. The accelerations measured in the port stern tube seal and the bow were reduced by a factor of 9.6 and 23 respectively from those in the starboard stern tube seal.
3. The shaft acceleration (as measured by the proximity probes) was approximately 50% less than the structural accelerations measured.
4. The peak structural acceleration measured occurred at approximately the same time as the peak intermediate bearing load.

Data Base and Analysis Procedure

Two extreme events were analysed:

1. Maximum Thrust (Test 09)
2. Heavy Ice Milling (Test 28)

The data analysed included the output of the vertical accelerometers, the vertical load on the aft intermediate bearing and the acceleration of the shaft as measured by the proximity probes located at the stern tube seal (Section 6.7). Comparison of these responses results in the determination of the influence of structural vibrations on the bearing reactions.

Results

Maximum Thrust (Test 09)

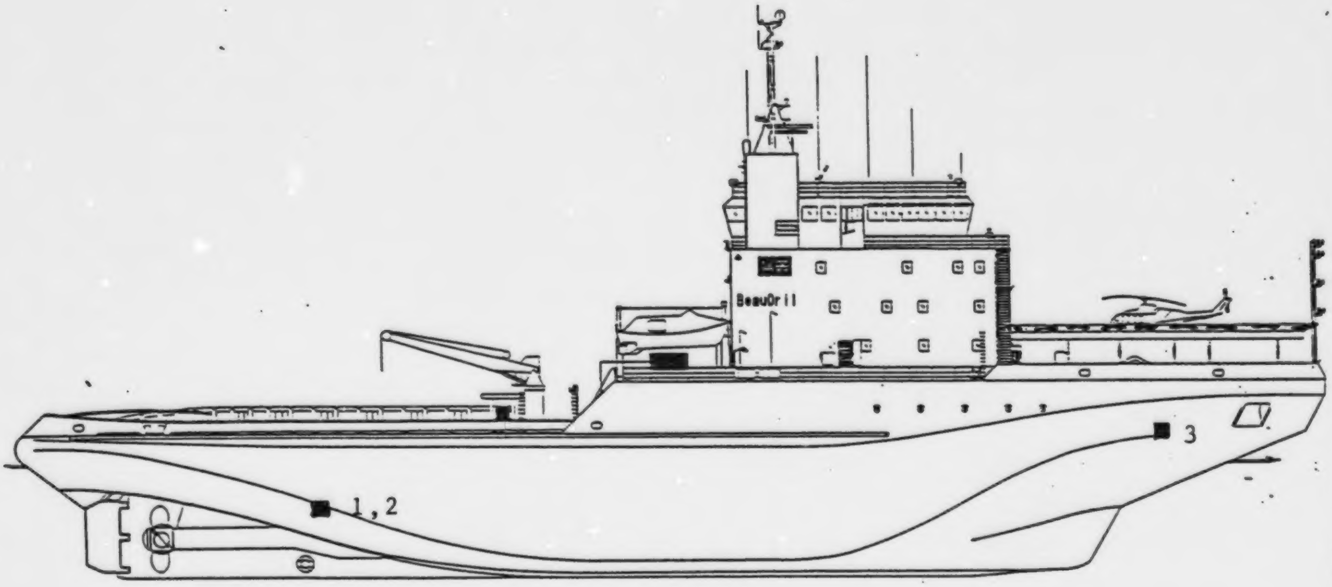
Figure 6.9.2 shows the measured vertical accelerations of the ship's structure during the event of maximum thrust (Test 09). The maximum acceleration of 3.5 m/s^2 was recorded by the starboard aft accelerometer. The forward and port aft accelerometer had maximum accelerations of 1.5 and 2.0 m/s^2 respectively. Therefore, the vibrations originating from the starboard shaft were dampened by a factor of 1.75 and 2.0 at the port aft and the bow respectively. Figure 6.9.3 illustrates the vertical shaft acceleration and the vertical load on the aft intermediate bearing for the same event. The maximum vertical shaft acceleration measured was 1.8 m/s^2 which is 50% of the vertical accelerometer output.

Heavy Ice Milling (Test 28)

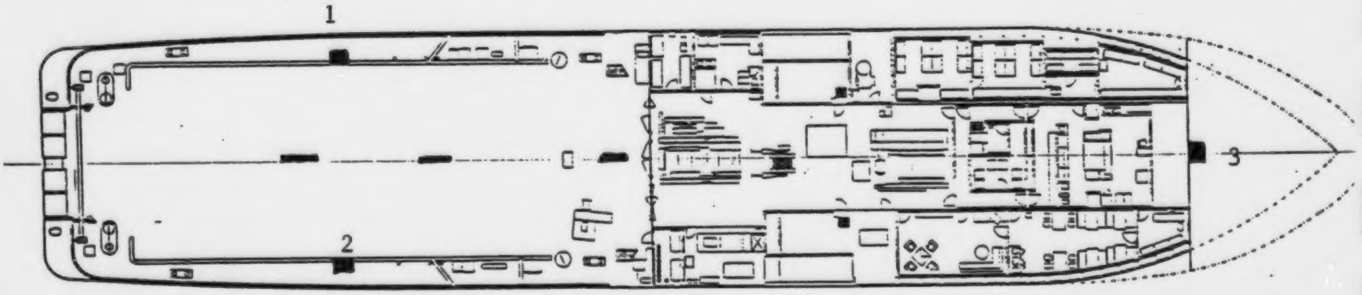
Figure 6.9.4 shows the measured vertical accelerations of the ship's structure during heavy ice milling. Figure 6.9.5 illustrate these accelerations from 2.2 to 3.2 seconds. The maximum acceleration of 11.5 m/s^2 was recorded by the starboard aft accelerometer. The forward and port aft accelerometers had maximum accelerations of 0.5 and 1.2 m/s^2 respectively. Therefore, the vibrations originating from starboard shaft were dampened by a factor of 9.6 and 23 at the port aft side and at the bow respectively. Figure 6.9.6 illustrate the vertical shaft acceleration and the vertical load on the aft intermediate bearing for the same event. The maximum vertical shaft acceleration measured was 4.8 m/s^2 which is 42% of the measured structural vertical acceleration.

The peak structural acceleration occurs at approximately the same time as the maximum vertical load on the aft intermediate bearing for both events studied.

M.V. "Kalvik"



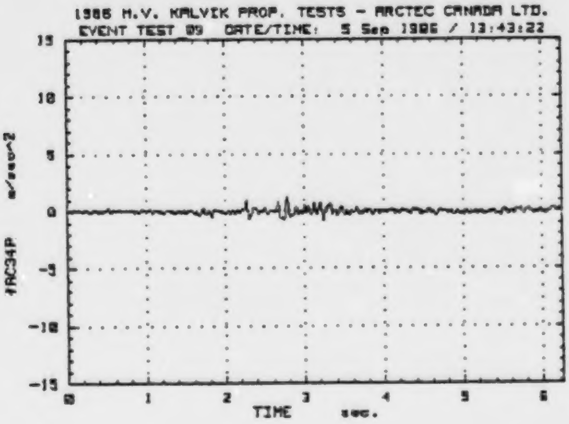
GENERAL ARRANGEMENT



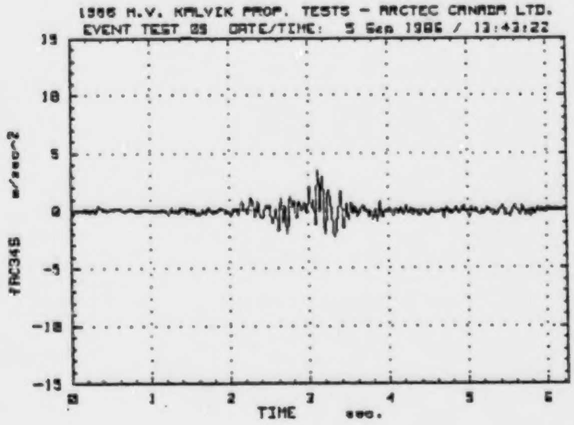
MAIN DECK

Figure 6.9.1 Location of Vertical Accelerometers

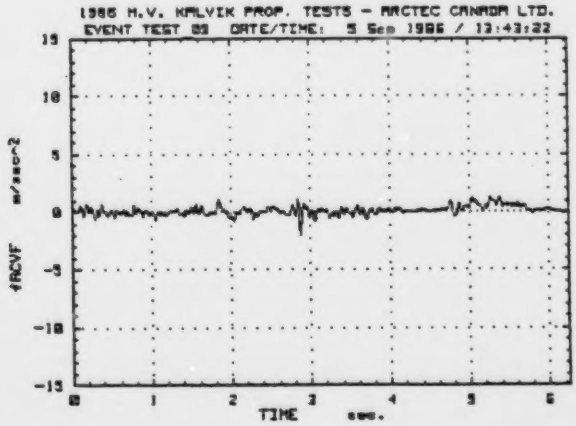
1,2,3 - Vertical Accelerometers



Port Aft Acceleration



Starboard Aft Acceleration



Bow Acceleration

Figure 6.9.2 Structural Vertical Accelerations - Test 09

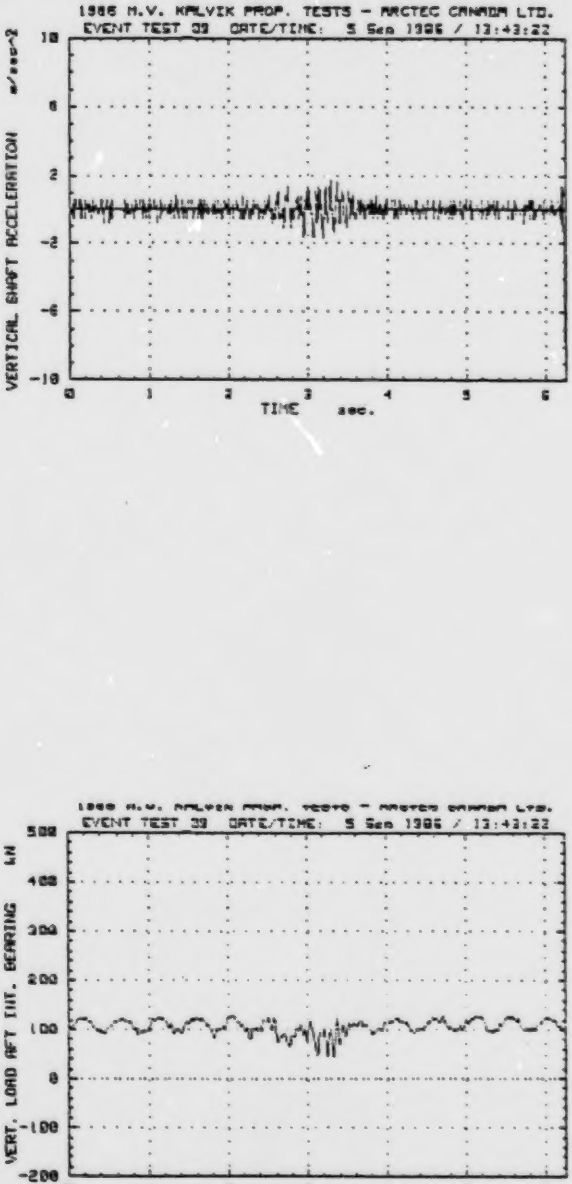
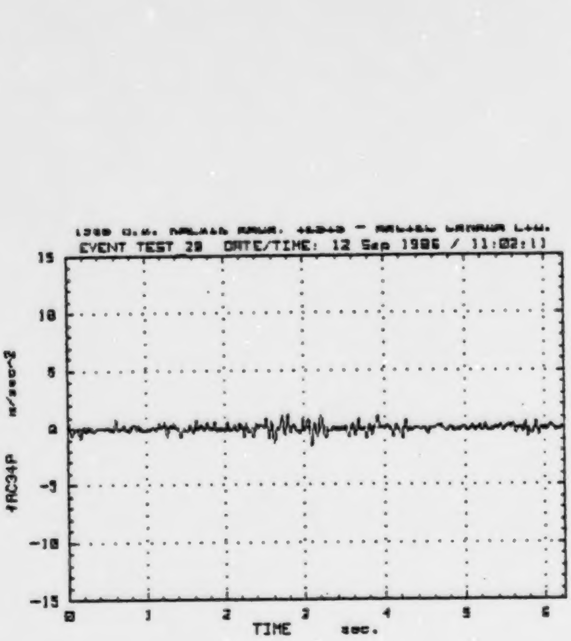
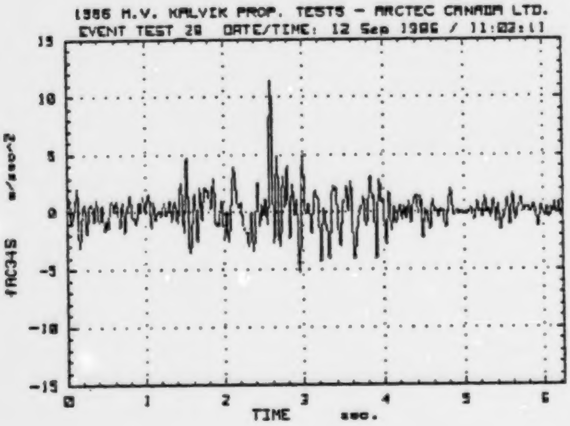


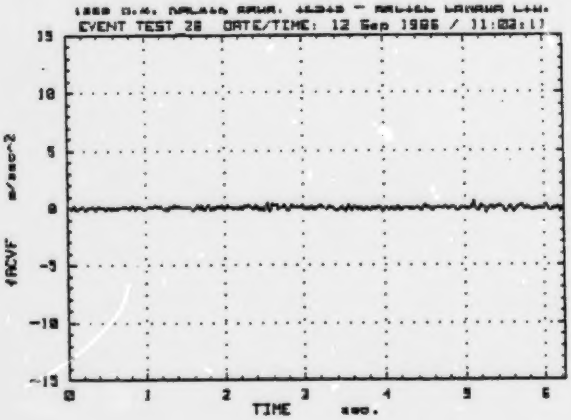
Figure 6.9.3 Shaft Vertical Accelerations and Vertical Load on Aft Intermediate Bearing
- Test 09



Port Aft Accelerations

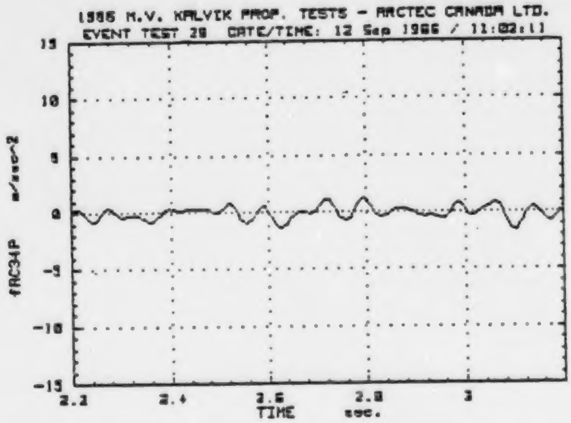


Starboard Aft Accelerations

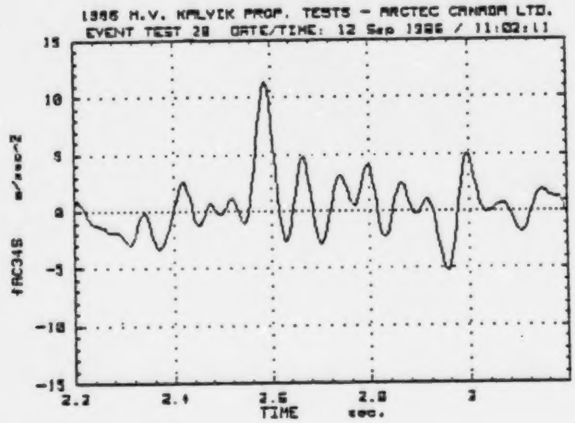


Bow Accelerations

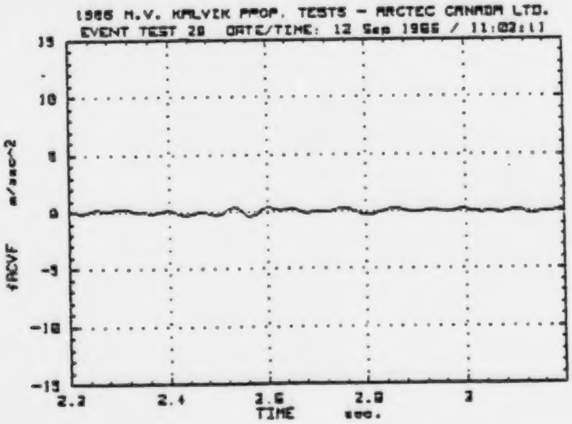
Figure 6.9.4 Structural Vertical Accelerations - Test 28



Port Aft Accelerations

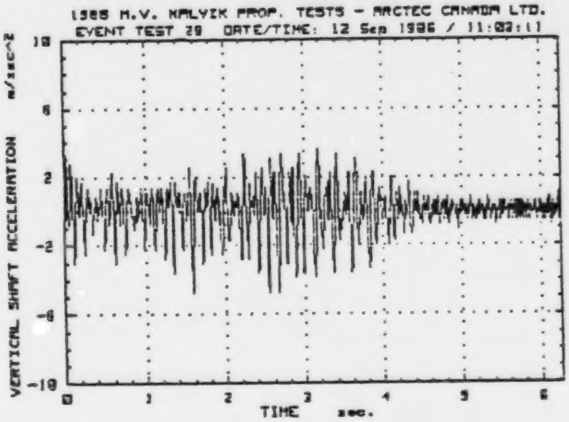


Starboard Aft Accelerations



Bow Accelerations

Figure 6.9.5 Structural Vertical Accelerations 2.2 - 3.2 seconds - Test 28



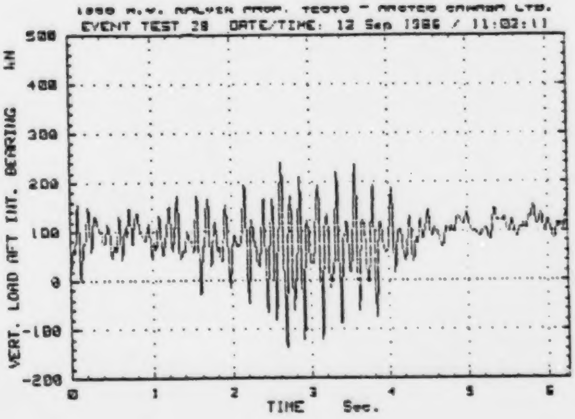


Figure 6.9.6 Vertical Shaft Accelerations and Vertical Load on Aft Intermediate Bearing - Test 28

6.10. Effect of Hull Bending

Introduction

This section details the analysis of the data collected during dedicated ramming tests. Three vertical accelerometers were installed at the port and starboard shaft tunnel and in the bow of the M.V. Kalvik to assess the inertial forces of the vessel. Longitudinal deck bending gauges were installed at three longitudinal locations at the aft end of the vessels to measure the flexure of the hull during a ramming event. Figure 6.10.1 illustrates the location of these sensors. Corresponding measurements of the response of the propulsion system were also recorded. These measurements were used to assess the effect of the bending of the hull during ramming on the reactions of the bearings and the shafting.

Data Base and Analysis

Seven ramming tests were conducted on September 12, 1986. Data was recorded at 100 readings/sec/channel for 31.25 seconds. The M.V. Kalvik impacted a ridge of multi-year ice with a thickness of 9 meters at velocities from 2 to 4 m/sec (4-8 knots). The heaviest ram recorded (Ram 5) was selected for analysis. This ram had an impact velocity of 4 m/sec (8 knots) and produced the highest deck bending stress recorded.

Figure 6.10.2 illustrates the stresses recorded at Frame 68, Frame 43 and Frame 26 for the duration of the ram. Open water conditions were present for the first 10 seconds, the impact phase of the ram occurred from 9 to 11 seconds. The beaching phase of the ram was from 11 to 25 seconds. This phase produced as high a deck bending strain as the impact phase. At Frame 68 the maximum strain of 80 μstrain (approximately 8% of the yield strength of the deck) was measured.

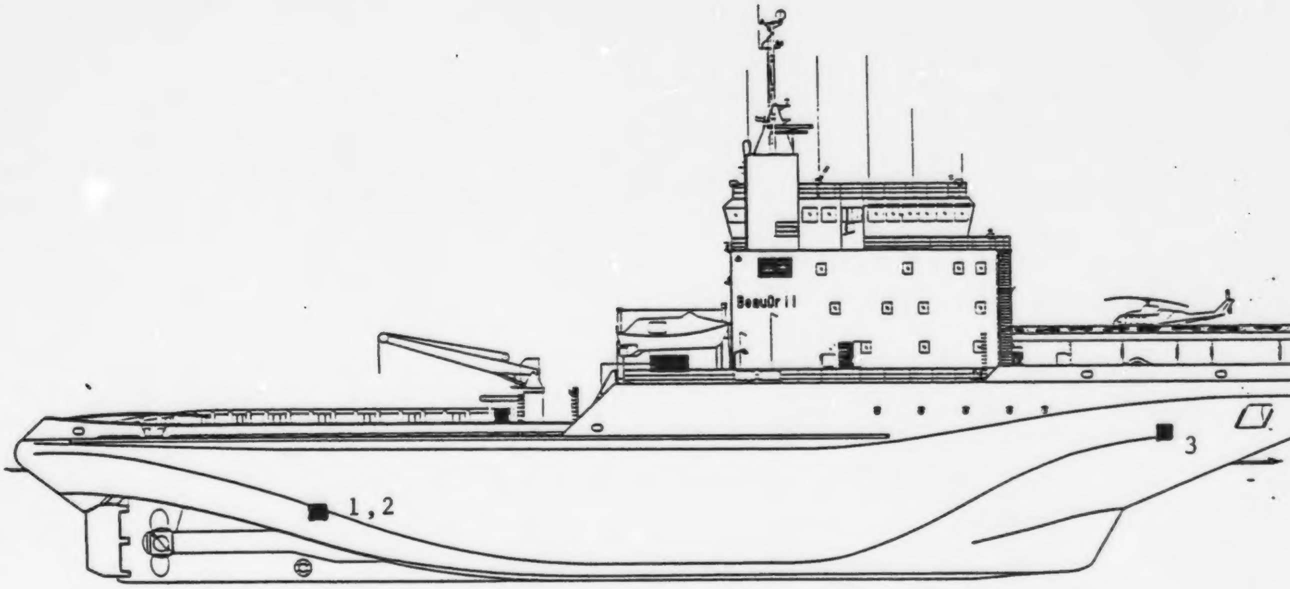
Figure 6.10.3 to Figure 6.10.5 illustrates the vertical and transverse load on the intermediate bearings during the ramming event. The loads change less than 30 kN (3 tonnes) during ramming. This compares with changes of 240 kN (tonnes) during ice milling (Section 6.5).

Figure 6.10.6 illustrates the shaft displacement measured at the stern tube seal forward of the forward stern tube bearing (see Section 6.7). The figure indicates that there is no significant change in the movement of the shaft due to the ramming of the heavy ice feature.

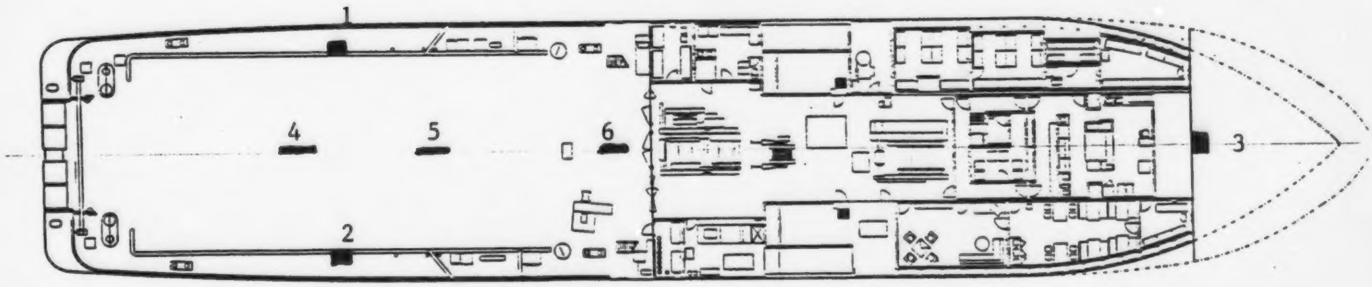
Figure 6.10.7 illustrates the accelerations measured during the ramming test. The maximum vertical acceleration measured was -4 m/sec^2 at the bow of the vessel. The vertical acceleration measured at the port and starboard shaft tunnels did not change significantly from the open water condition.

Conclusions

1. Ramming does not have any significant effect on the shaft line loads especially when compared with ice milling loads.
2. The stern of the ship has not been accelerated during the most severe ram and inertial loads have not been generated in the shaft line.
3. Shaft motions, bending and bearing loads during the ramming did not change from the open water values.



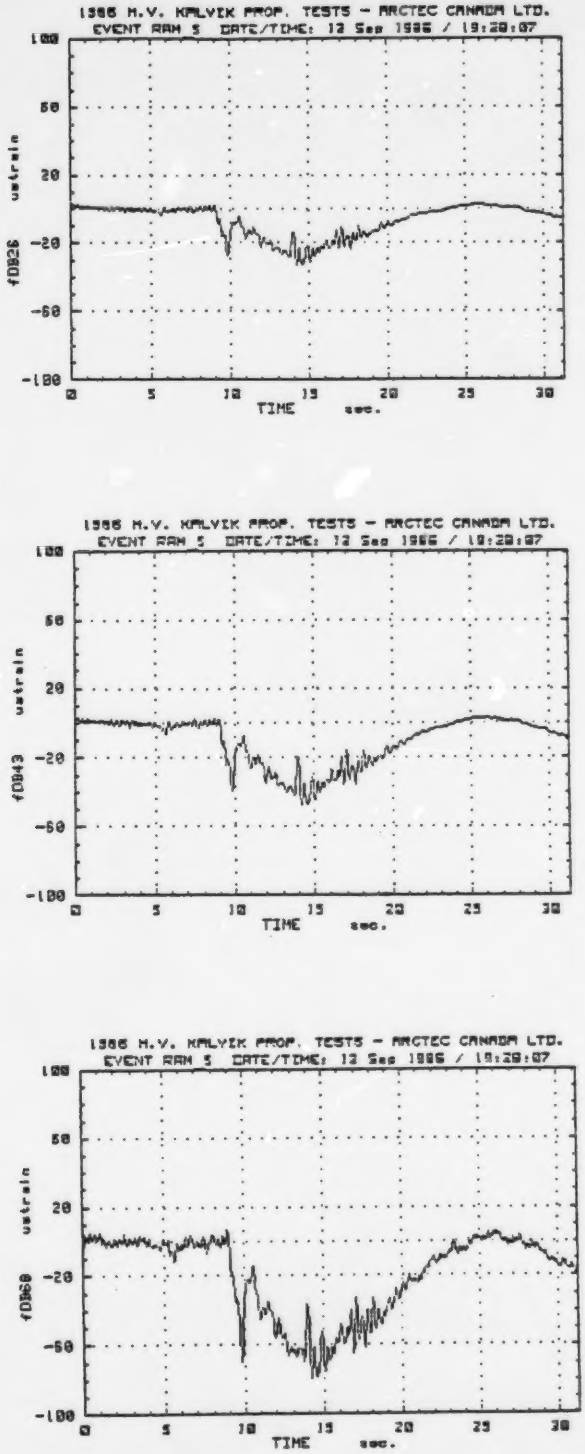
GENERAL ARRANGEMENT



MAIN DECK

Figure 6.10.1 Location of Accelerometers and Deck Bending Gauges

1,2,3 - Vertical Accelerometers
4 - Deck Bending Gauge Frame 26
5 - Deck Bending Gauge Frame 43
6 - Deck Bending Gauge Frame 68

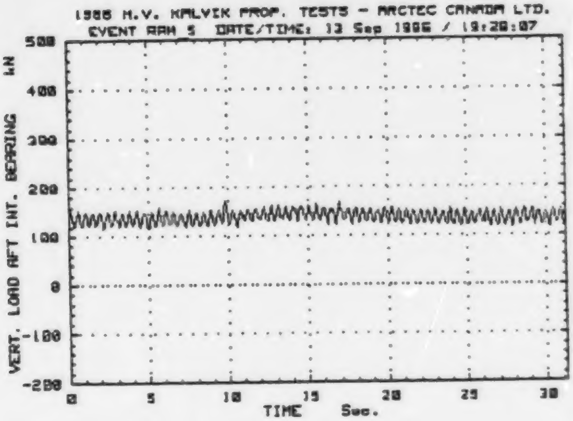


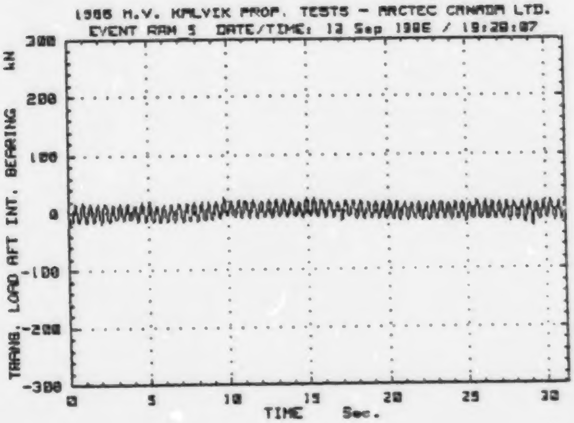
Frame 26

Frame 43

Frame 68

Figure 6.10.2 Deck Bending Strains - Ramming





Port

Stbd

Figure 6.10.3 Vertical and Transverse Load
- Aft Intermediate Bearing
- Ramming

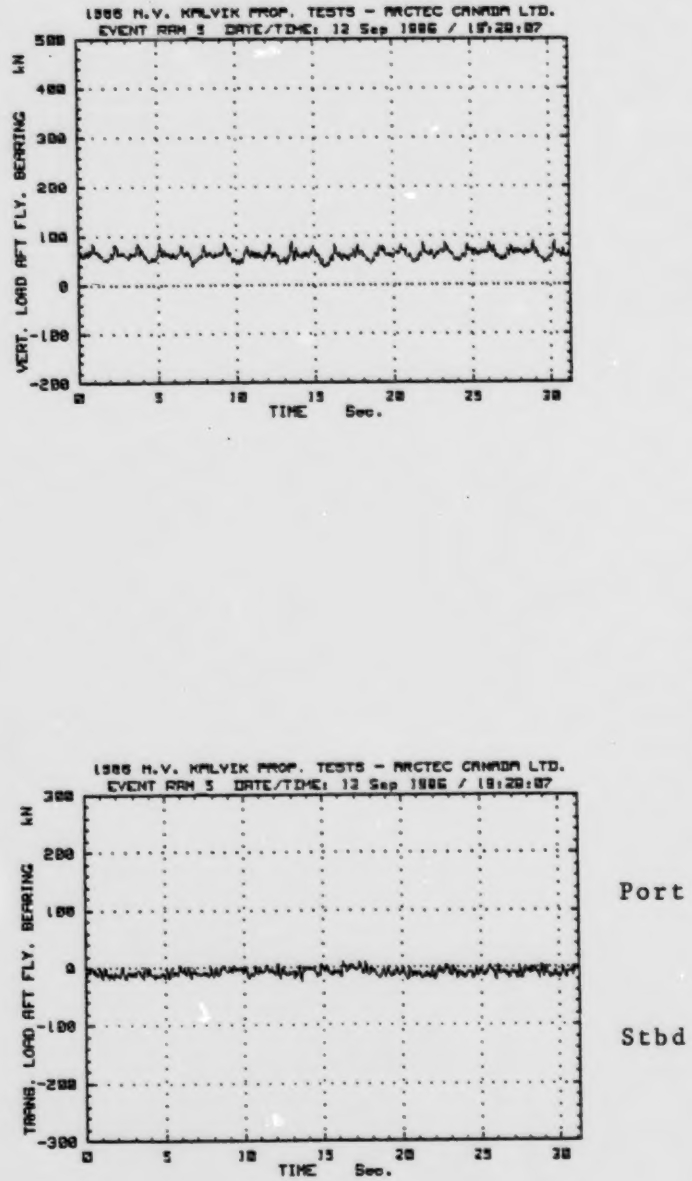


Figure 6.10.4 Vertical and Transverse Load
- Aft Flywheel Bearing
- Ramming

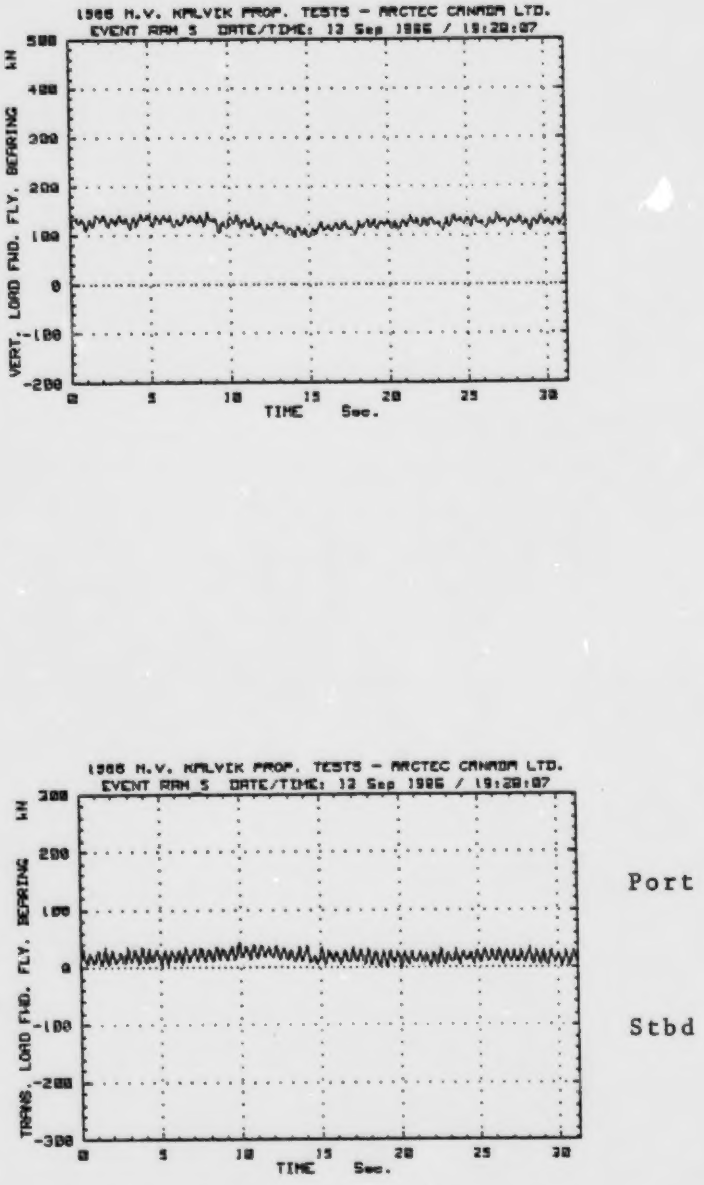


Figure 6.10.5 Vertical and Transverse Load
- Forward Flywheel Bearing
- Ramming

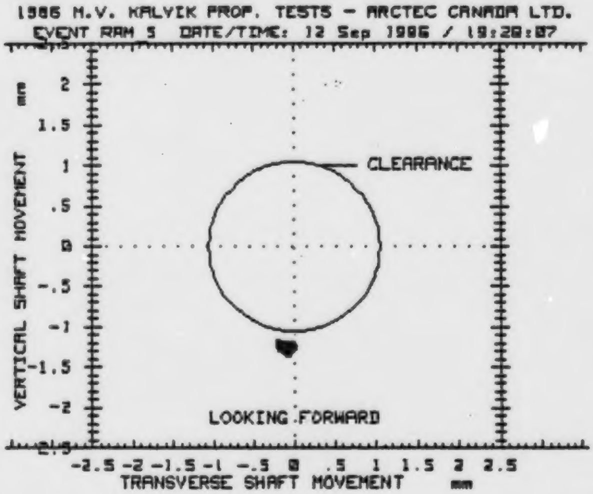


Figure 6.10.6 Shaft Displacement at Stern Tube Seal - Ramming

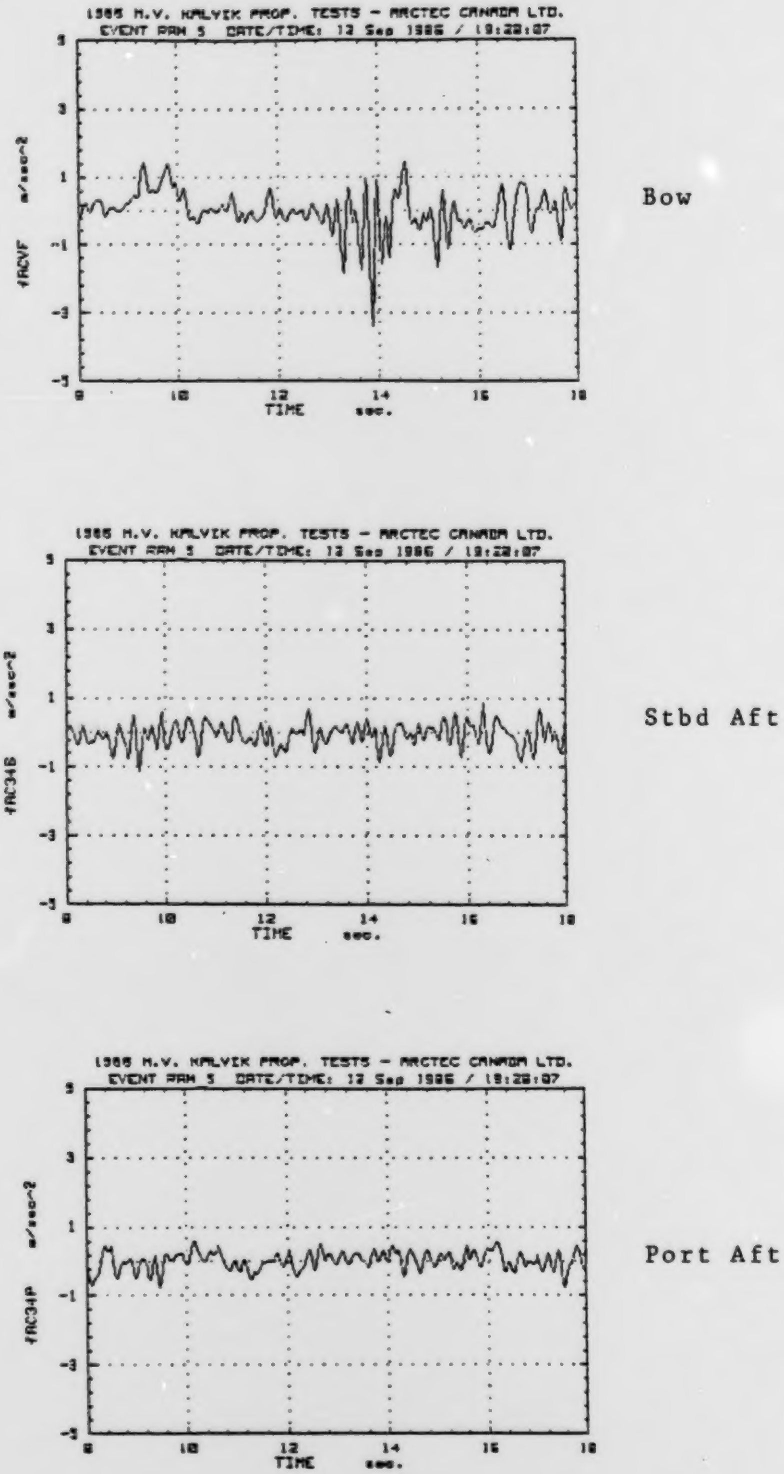


Figure 6.10.7 Vertical Acceleration
- Ramming

6.11 Gyroscopic Reaction on Flywheel Bearings

When a rotating flywheel is being moved away from its stationary rotational axis (see Figure 6.11.1), a moment is generated in its bearing opposing that acceleration.

Denoting ω_o as the angular velocity of the rotating flywheel and ω' as the angular velocity of the accelerating ship (heaving upwards under the ice impact force), and by I the inertia of the flywheel, the following formula expresses the magnitude of the moment M being the result of the "gyroscopic effect":

$$M = I \times (\omega' \times \omega_o) \quad [kgm^2/s^2]$$

Note that the **vertical** angular velocity results in a **horizontal** reaction force in the bearings (see Figure 6.11.1). If we denote R as a horizontal reaction in the flywheel bearing due to the gyroscopic effect, we'll have

$$M = R \cdot L ,$$

where L is the distance between the bearings.

In order to estimate the reaction forces due to the gyroscopic effects, the following calculations are performed:

$I = 18, 154\ kgm^2$ (after reference 1)

$\omega_o = 2\,\Pi \times 130\ rpm/60 = 13.61$ rad./sec.

Mass of flywheel 12,000 kg;

(distance between the bearings $L = 2.5$ m (see DWG 61-00-01).

In the most severe ramming event recorded (Ram 5), the recorded maximum acceleration of the bow was 0.43 g, and the impact lasted for approximately 0.2 secs. Under the assumption that the ship rotated about the axis passing thru the point located 2/3 L aft from the forward perpendicular, the angular velocity can be estimated to be:

$\omega' = V_{vert} / (2/3\ L - 2/5L) = 0.05\ V_{vert}$; and, putting L = 75 m,

V_{vert} = acceleration $_{max}$ x $(^t / T)$,

where t is the time and T is the duration of the impulse. At the end of the impulse

V_{max} = acceleration $_{max} \cdot T/2$, (since the impulse has a triangular shape).

Putting T = 0.2 sec (from the accelerometer plot),

we obtain

$$\begin{aligned} V_{max} &= 0.43 \times 9.81 \times 0.2/2 = 0.42\ m/s \\ \omega &= 0.42\ m/s \times 0.05 = 0.021\ rad./s \\ M &= 18{,}154 \times 0.0245 \times 13.61 = 5211\ Nm \\ R &= 5211\ Nm/2.5 = 2084\ N \end{aligned}$$

Note that the reaction forces are not dependent on the position of the flywheel with respect to the support bearings.

The force of 2.0 kN is very small in comparison with the static bearing load of approximately 154 kN.

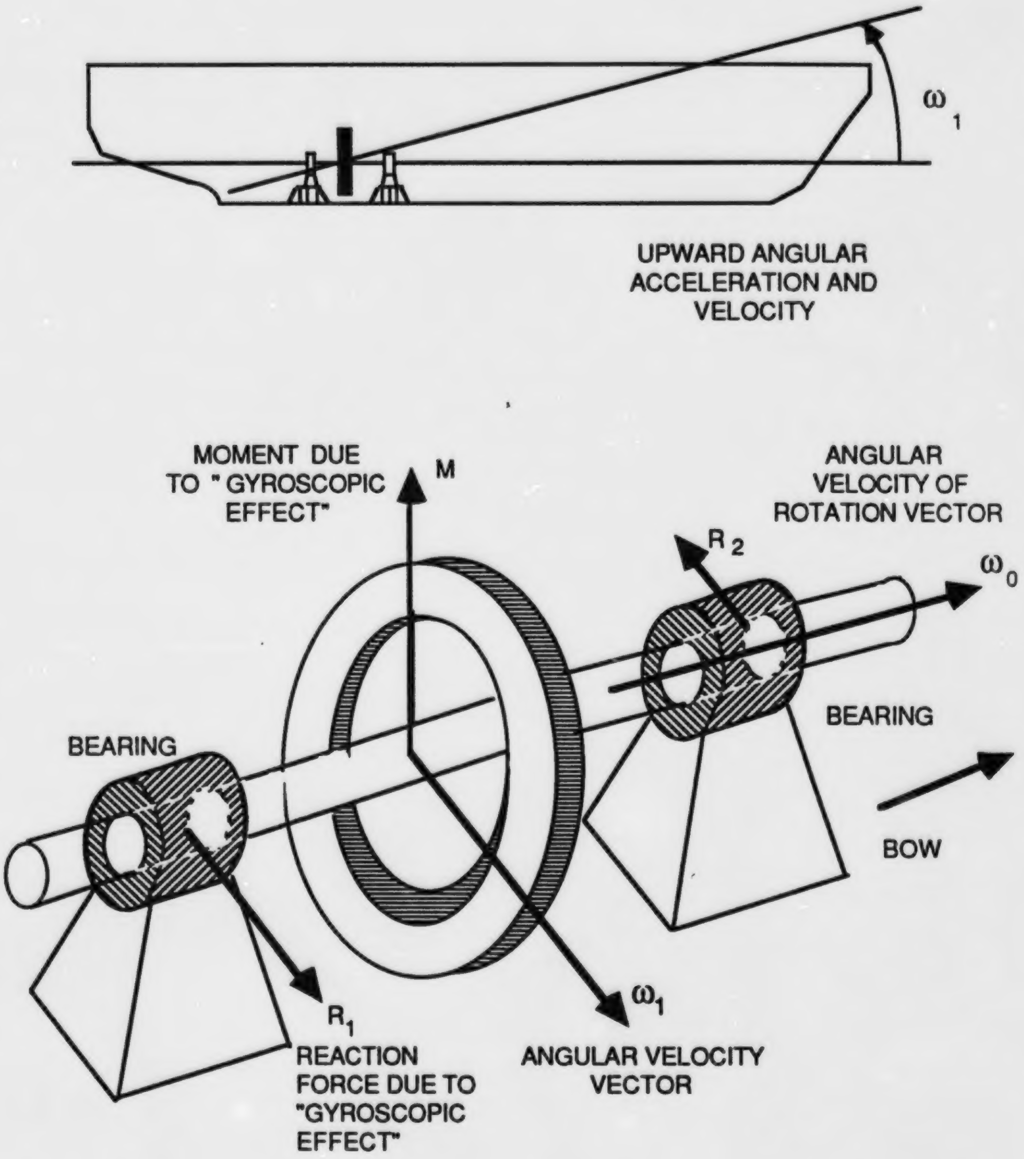

ω
1
UPWARD ANGULAR ACCELERATION AND VELOCITY
MOMENT DUE TO "GYROSCOPIC EFFECT"
M
ANGULAR VELOCITY OF ROTATION VECTOR
R 2
ω 0
BEARING
BEARING
BOW
R 1
REACTION FORCE DUE TO "GYROSCOPIC EFFECT"
ω 1
ANGULAR VELOCITY VECTOR

FIGURE 6.11.1 GYROSCOPIC EFFECT OF THE FLYWHEEL

6.12 Ice Forces on Propeller

Introduction / Summary

The propeller blades of the M.V. Kalvik were damaged in the 1983 operating season. The blades on both port and starboard propellers were bent forward from .5 radius upward and from 20 to 95 mm. An estimate of the maximum ice force on the propeller blades is determined in this section.

The shaft thrust movement was used for the assessment of the ice loads on the blades as the ice induced forces were not measured directly on the propeller. In addition, an analysis of the data is performed in order to assess the ice milling process, geometry and characteristics.

The propeller of the M.V. Kalvik has the following characteristics:

- Power delivered	8088 kW
- Diameter	4.8 m
- Number of blades	4
- Hub/Diameter ratio	0.417
- Pitch ratio	1.04
- Propeller type	CPP
- Manufacturer	LIPS NV.
- RPM, at MCR	130
- Yield Stress	260 MPa
- Ultimate Tensile Strength	660 MPa

The analysis of the data gave the following results:

1. Maximum longitudinal ice load on one blade is estimated at 2.3 MN (235 tonnes). Under this load applied at 0.9 radius, the onset of yielding of the blade would occur at 0.6 radius.

2. The maximum transverse load on one blade was estimated at 1.12 MN (113 tonnes).

3. Approximately 2/3 of the blade is immersed in ice during the milling process, therefore the depth of cut is approximately 0.93 m.

4. The angle of sweep during milling is approximately 100 degrees.

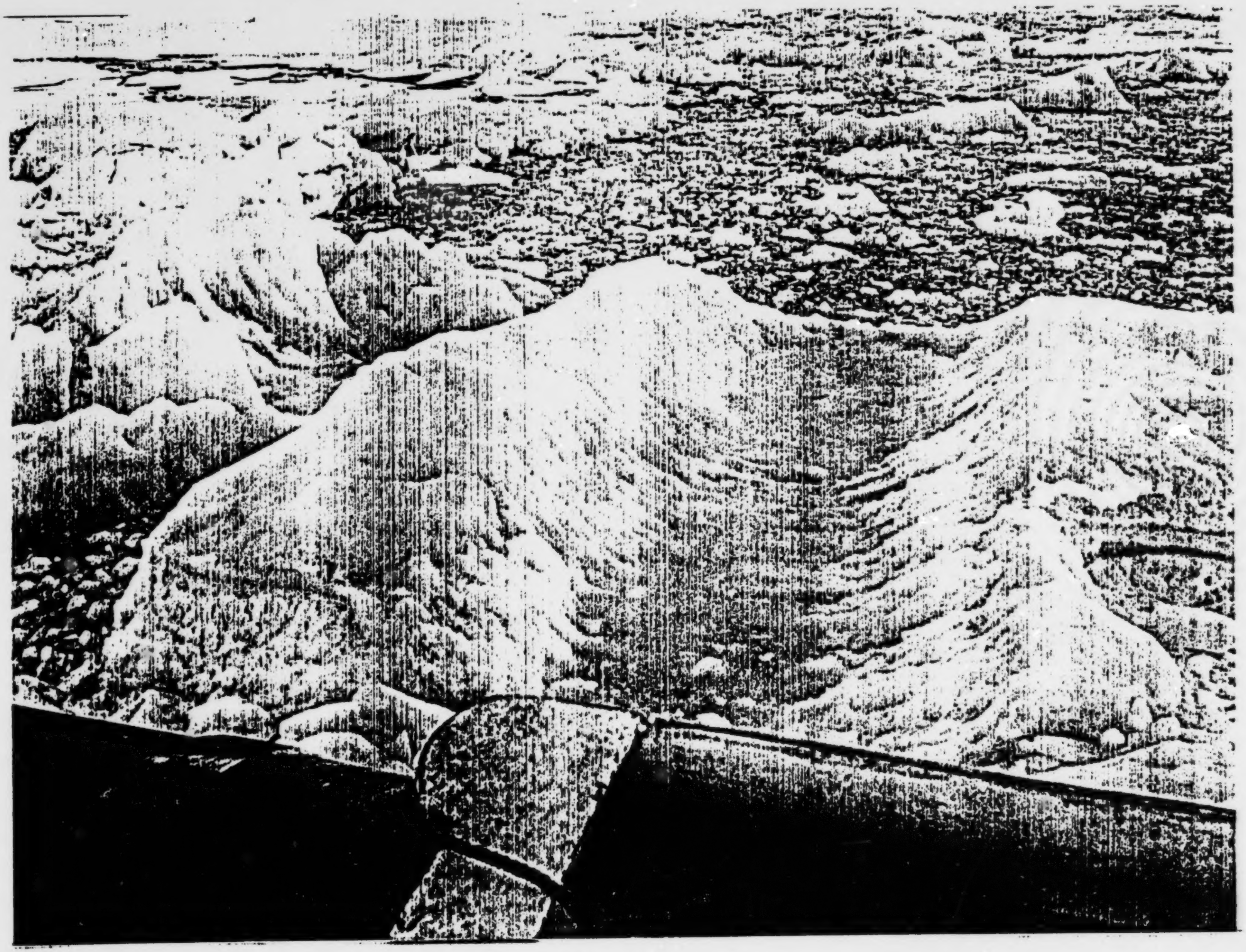


Figure 6.12.1 Milled Ice Block

Instrumentation and Measurement Procedure

The instrumentation of shaft for thrust measurements is documented in Section 6.6. The geometry of milling process is obtained by a direct comparison with the geometry of the propeller.

Data Base

The statistical analysis showed that the event Test_09 contained the maximum ahead thrust signal of 2.2. MN, and the event Test_28 contained the maximum astern thrust signal of -2.25 MN. These events are used in analysing the extreme ice forces on the propeller blades. A description of these events and the corresponding propulsion machinery response is contained in Sections 6.3, 6.5, 6.6, and 6.7.

Figure 6.12.1, a photograph of a milled ice block, was used for computations of milling process characteristics.

Analysis Procedure

Longitudinal Ice Force on Blades

The total thrust acting on the propeller during the milling process is composed of two elements: hydrodynamic load and ice milling load. The hydrodynamic load is evenly distributed between the four blades, has a quasi-static character, and is expressed as:

Hydrodynamic Force (Fh)= Mean Thrust /4.

This thrust is located at approximately 0.734 relative radius and does not contribute significantly to the bending of the upper part of the blade.

The ice load can act on one or more blades. In order to assess how many blades are milling ice at a time, Figure 6.12.1 has been analysed and the following has been established:

Depth of Cut = 0.93 m
Ratio of the depth of cut to the radius of cut in ice = 0.37
Time for each blade to cut through ice = 0.13 seconds
Centre of immersed area in ice is 0.47 m from the blade tip

The time for the shaft thrust variations is approximately 0.12 seconds (Section 6.6) which corresponds well with the time for each blade to cut through the ice. Therefore, the ice force and the corresponding thrust variation can be attributed to ice impacting on one blade.

In addition, the following information can be extracted from Figure 6.12.1:

Approximately 40 cuts were made through the ice block, which corresponds to an ice milling duration of:

$$T = (40/4)x(60/130) = 18.5 \text{ sec}/4 = 4.6 \text{ sec}.$$

The length of this ice block is estimated to be 8 m. Therefore, the speed of advance of propeller against the ice block was:

$$V_s = 8/4.6 = 1.7 \text{ m/sec} \ (3.4 \text{ knots}).$$

Maximum Stress of Propeller Blade

Having established that the whole ice induced thrust can be attributed to one blade we can formulate the following equation:

Ice force on one blade = Measured Shaft Thrust - Open Water Thrust

Maximum Ice force = -2.2 MN - 0.1 MN = -2.3 MN (astern thrust) (Test 28)

This load produces the following bending stresses:

$\text{Stress} = \frac{M}{SM}$ where $M = Fx$;

F	Ice Force on Propeller Blade
x	Distance between the point of application of the ice force and the section at which bending stress is calculated
SM	Section modulus of the blade

$$SM = (0.1)CT^2$$

$CT^2_{0.6} = 47{,}565 \text{ cm}^3$ CT^2 for M.V. Kalvik at 0.6 radius

$$SM = 0.0047565 \text{ m}^3$$

x is calculated as follows:

$$x = (0.9 - 0.6)R = 0.3 \times 2.4 \text{ m} = 0.72 \text{ m}.$$

The stress in the section at 0.6 R is

$$\textbf{Stress} = \frac{2.3 \times 10^6 \times 0.72}{0.0047565} = \textbf{348 MPa}$$

This stress exceeds the yield stress of the material (260 MPa.) by 34%.

Thus the yield has been exceeded and the permanent deformation has set in.

Transverse Loads on Propeller

In order to assess the magnitude of the ice impact force acting in the plane of the propeller disc the following calculations are performed:

Depth of cut = 0.93 m
Mean width of blade = 2.0 m
1/4 of leading edge of blade in contact with ice
Maximum measured force = 2.3 MN

Therefore:

Contact area of ice on blade = (0.93)(.25)(2) = 0.45 m^2

Pressure = 2.3/0.45 = 5.1 MPa

Projected area of blade = (0.45)(sin(20°) = 0.154 m^2

Thickness of leading edge times contact length = (0.070)(0.93) = 0.0651 m_2

Total Transverse Force = (5.1)(.154)+(5.1)(.065) = **1.12 MN (113 tonnes)**

This calculation agrees well with the transverse forces estimated on the aft stern tube bearing (1.1 - 1.6 MN).

Results

1. Approximately 2/3 of the blade is immersed in ice during the milling process.
2. The angle of sweep during milling is approximately 100°.
3. Duration of one blade pass through ice block is approximately 0.13 seconds.
4. One blade carries all of the ice load.
5. The maximum ice load gained by one blade is estimated to be 2.3 MN.
6. Under this load, the blade started to yield at relative radius of 0.6.
7. The maximum estimated transverse load on one blade = 1.12 MN (113 tonnes).

7. ANALYTICAL MODELS (TASK 5 con't)

Introduction / Summary

The ability to predict the loading and response of a propulsion system under dynamic ice loads is essential to the development of reliable and save icebreaker propulsion systems. The development and validation of propulsion models requires an extensive study of full scale data and a sensitivity analysis of the model parameters. The structure of torque, thrust and alignment models and method of development are described in this section, with some illustrated sample results. Further development of these analytical models is recommended for a future follow-on project.

Models describing shaft torque and thrust have been developed by Arctec Canada Limited personnel for the M.V. Robert Lemeur propulsion system under contract to Transport Canada. They were used to predict the loading on the propeller blades given measured shaft torque and thrust variations during ice/propeller impacts. The models were also used to assist in the understanding of the propeller-ice interaction, and analyse the effect of varying parameters (such as stiffness and inertia) on the response of the system to ice loads.

The thrust and torque models developed for the M.V. Kalvik are based on these previous models. The results from executing the thrust model indicated that the longitudinal force on the propeller blade is approximately equal to the measured increase in shaft thrust. The results from using the torque model indicated that the measured shaft torque is approximately 65% of the torque on the propeller blades.

7.1 Thrust Model

Conceptual representation of the shaftline for longitudinal vibrations model is shown in Figure 7.1.1. The system has three-degrees-of-freedom which has been proven to be sufficient on the M.V. Kigoriak and M.V. Robert Lemeur projects.

Propeller and a part of the tailshaft mass are combined together in the first lumped mass element. The remaining part of the tailshaft and the first intermediate shaft are combined in the second lumped mass element. The flywheel and the third intermediate shaft mass are combined in the third lumped mass element. The thrust pad is considered to be an infinitely stiff support. In a similar fashion, the shaft stiffness are combined for tailshafts and intermediate shafts.

The masses of the shafts were calculated using the following formula:

$$m = \rho\,(\pi)(d_o^2 - d_i^2) \times L/4$$

where ρ is the density of shaft material, d_o is the outer shaft diameter in meters, d_i is the inside shaft diameter in meters, L is the shaft length in meters.

For the propeller, an additional 60% of its mass is included to account for the added mass effects.

The stiffness of an element is calculated using the following formula:

$$k_i = EA_i / L_i$$

where E is the elastic modulus of the shaft's material, A_i is the cross sectional area of the shaft and L_i is the shaft's length.

Table 7.1.1 gives the summary of system characteristics.

Table 7.1.1 Summary Characteristics of the Longitudinal Vibrations Model

MODE	ELEMENT	MASS (kg)	STIFFNESS (GN/m)
1	Propeller/tailshaft	79,548	6.028
2	Tailshaft/intermediate shaft	28,000	4.300
3	Flywheel/intermediate shaft	24,300	5.500

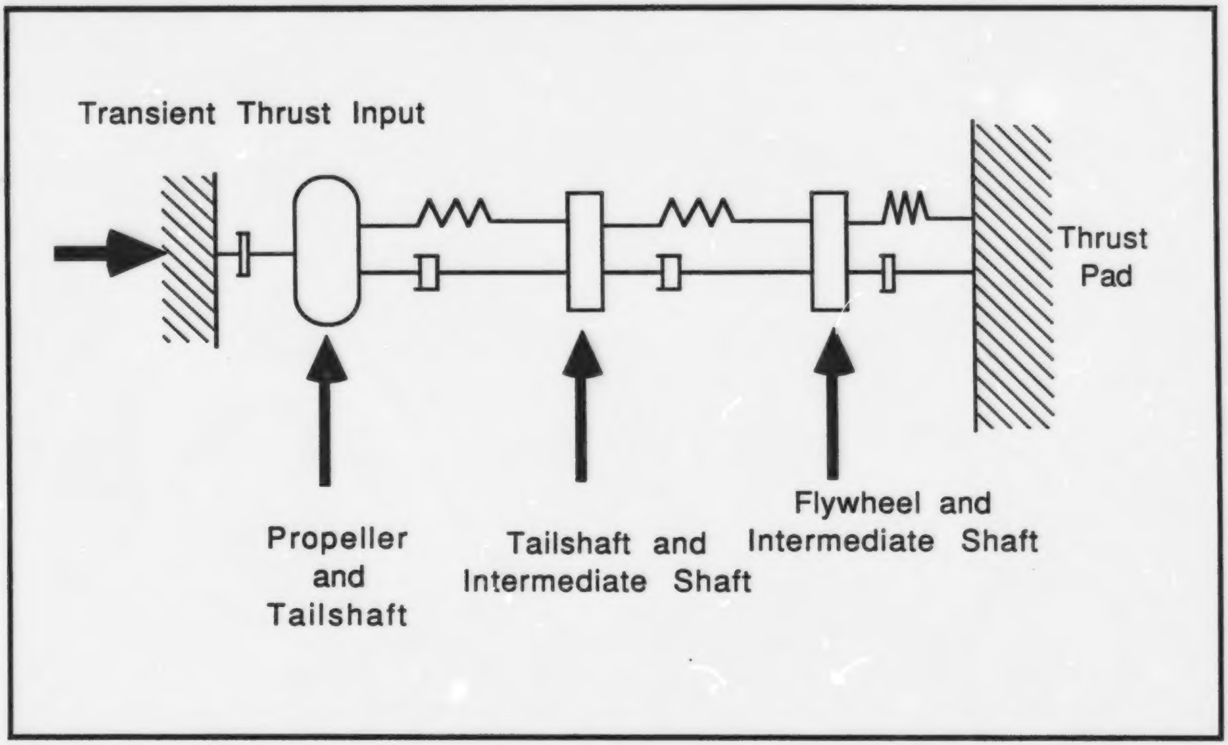

Transient Thrust Input
Thrust Pad
Propeller and Tailshaft
Tailshaft and Intermediate Shaft
Flywheel and Intermediate Shaft

Figure 7.1.1 Thrust Model

The differential equation governing the response (in longitudinal vibrations) of the shaft can be written as:

$$[M_i][\ddot{X}_i] + [C_i][\dot{X}_i] + [K_i][X_i] = \{F\}$$

$[M_i]$ - mass matrix
$[X_i]$ - Longitudinal movement of each element
$[C_i]$ - Shaft damping matrix
$[K_i]$ - Longitudinal stiffness matrix
$\{F\}$ - Input force matrix (propeller thrust).

Figure 7.1.2 illustrates the shaft thrust response calculated from the thrust model for an input propeller thrust variation of 2.0 MN (measured from Test 09). This figure indicates that the measured shaft thrust variation is approximately equal to the input thrust on the propeller.

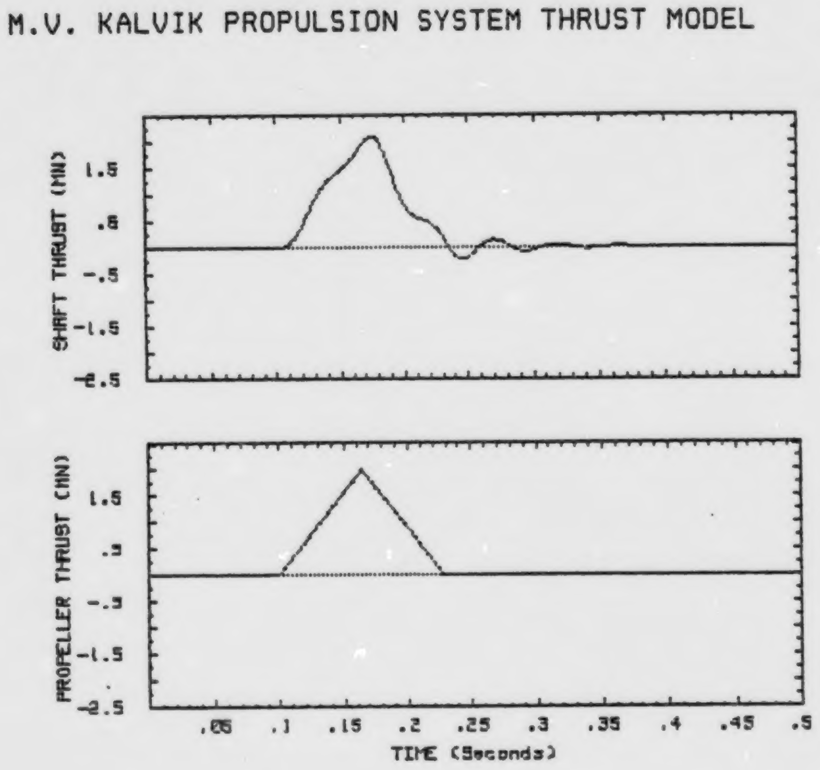


Figure 7.1.2 Shaft Thrust (Output)
Propeller Thrust (Input)
Thrust Model

7.2 Torsional Vibrations Model

The schematic representation of the torsional elements of the shaftline is shown in Figure 7.2.1.

The system is composed of:

- polar moments of inertia;
- torsional stiffnesses; and
- torsional damping coefficients.

Moments of inertia are calculated using standard formulas.

The torsional stiffnesses are calculated using the formula

$$k = I_p G/L,$$

where

I_p is the polar moment of inertia of the section of the element,
G is the modulus of rigidity of the material,
L is the length of the element.

As for all shaftline models having a gear contained in the system, all of the inertias and stiffnesses are reduced to the engine side. The reduction is based on the constant energy principle. Further, since there are two engines driving the gear, this branched system is reduced to the one line system.

The calculated characteristics of the system are listed in the Table 7.2.2.

Table 7.2.2 Summary Characteristics of the Torsional Vibrations Model

MODE	ELEMENT OF INERTIA	MASS MOMENT STIFFNESS (kgm)	TORSIONAL (MNm/rad)
1	Propeller and Tailshaft	1762	1.945
2	Flywheel and Intermediate shaft	849	2.625
3	Gears and Coupling	1019	0.540

The differential equations governing the shaft torsional behaviour is:

$$[I] \times [\ddot{\Phi}] + [C]\,[\dot{\Phi}] + [k]\,[\Phi] = \{Q\}$$

[I] - mass moment of inertia matrix
[C] - torsional damping matrix
[k] - torsional stiffness matrix
{Q} - input torque matrix (Propeller torque)
[Φ] – shaft twist matrix

Figure 7.2.2 illustrates the shaft torque response calculated from the torque model for an input propeller torque variation of 240 kNm from 0.13 seconds. This figure indicates that the measured shaft torque variation is approximately 65% of the input torque on the propeller for a short duration impact.

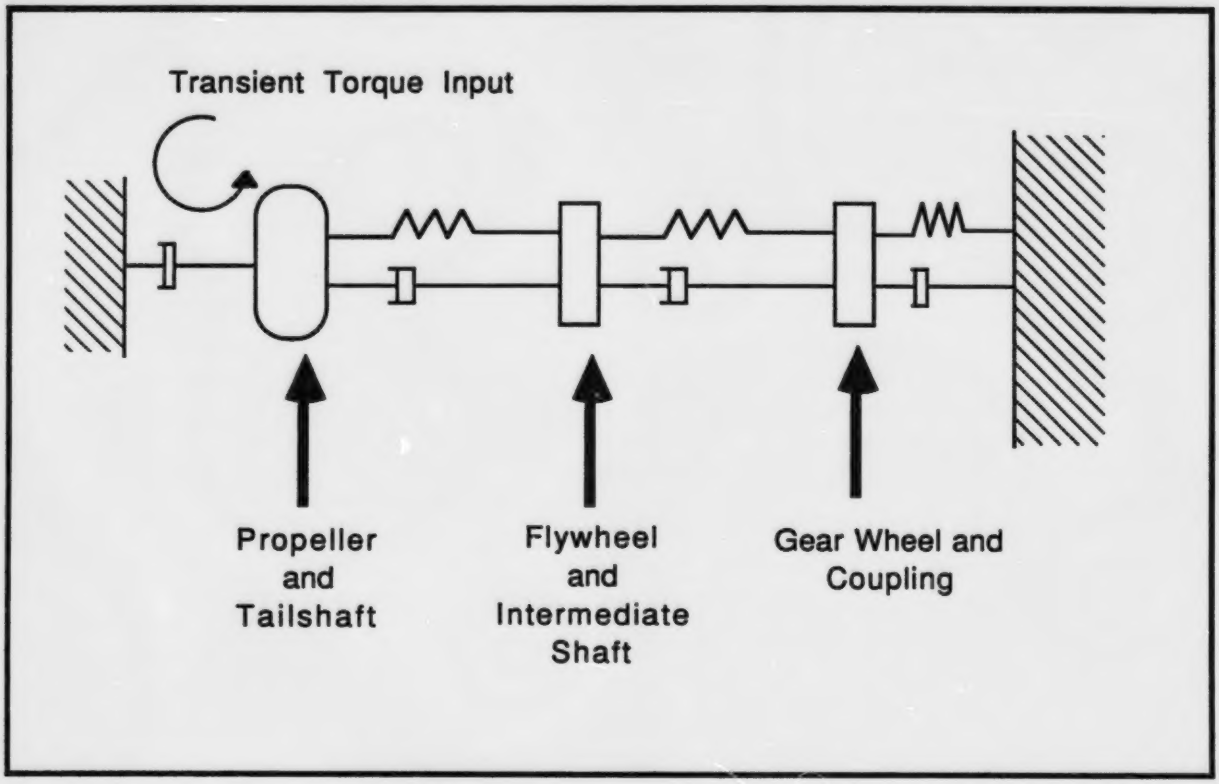


Figure 7.2.1 Torque Model

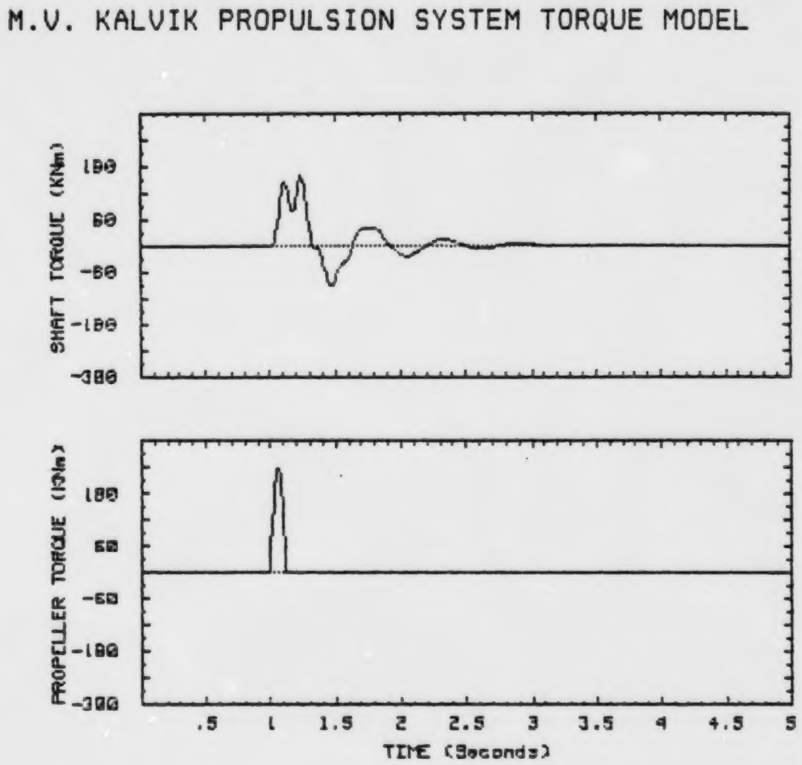


Figure 7.2.2 Shaft Torque (Output)
Propeller Torque (Input)
Torque Model

7.3 Shaftline Dynamic Alignment Model

The schematic representation of the shaftline model for transverse vibration calculations is shown in Figure 7.3.1.

The model is composed of the following elements:

- shaft and its elements:
  - bending stiffness;
  - mass distribution;
  - bending damping coefficient.

- supports and its elements:
  - support stiffness;
  - support mass;
  - support damping coefficient.

The stiffness of the bearing support and its damping coefficient may include the stiffness and damping coefficient of the lubricant (oil or water). In such a case, the combined stiffness and damping coefficients should be used. Shaft mass distribution is given by its actual weight distribution with the addition of the added mass for the propeller and the subtraction of the buoyancy (if any) of the tailshaft. Oil in the pipes should be included in the weight calculations.

A division of shaftline into small beam elements is necessary in order to solve the complex differential equations of motion.

Each beam element can be represented by a concentrated mass, bending and torsional stiffnesses (springs).

Bearings are represented by their stiffnesses defined as

$$K = F/y$$

where F is the load causing deformation y.

Higher degree of refinement is obtained when the stiffness is obtained from dynamic, rather than static calibration tests, since it may be found to be a function of the speed of load application.

Inputs to the model are:

Shaftline geometry, broken down to the geometry of each individual beam element:
- length;
- outside diameter;
- inside diameter.

Shaftline material properties:
- elastic modulus;
- Poisson ratio;
- mass density (including added mass);
- shear modulus.

Bearing's locations and their stiffnesses.

In-plane force time history (F(t).

As for the other models, each system having unique characteristics gives a unique transfer function: input-output and a unique inverse transfer function:

Output → Input

The outputs of the model are:

- bearing reactions time histories;
- bending moments;
- shear forces, and
- shaft movements/deflection distribution along the shafts at any point in time.

One particular case of the model applications is when the shaftline is subject to its own weight only. The static alignment case can then be solved and compared with that calculated by the classification society.

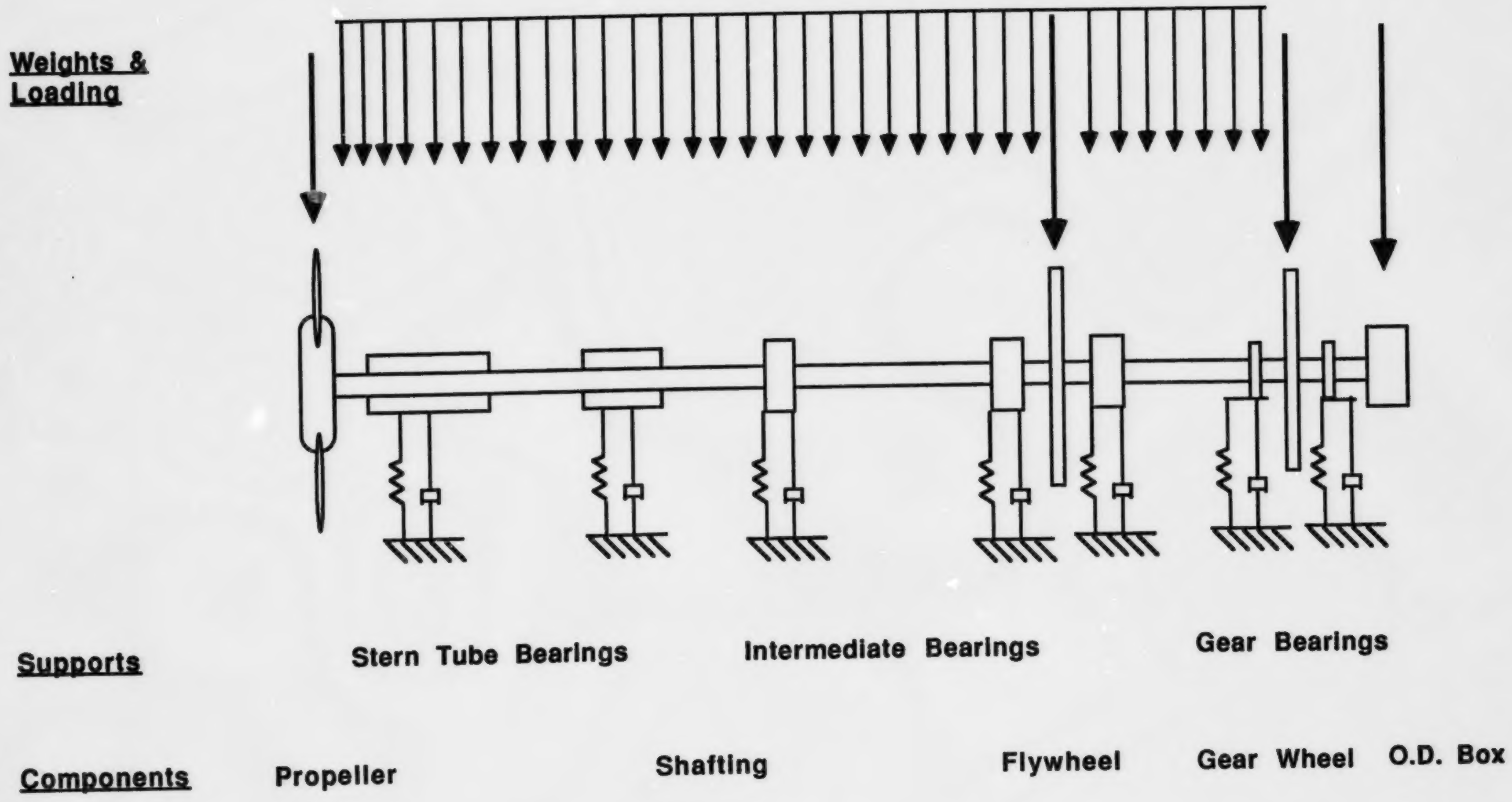


Figure 7.3.1 Alignment Model of a Propulsion System

8 CONCLUSIONS

It is important to bear in mind that the conclusions presented here are based upon the results of some 94 high speed recordings of propulsion system response collected over a period of about two weeks of ship operation. Of this data some 72 events, comprising on the order of 2000 individual propeller blade-ice impacts were recorded during approximately eight days of ship operation in severe multi-year ice conditions at or near the limit of the ship's navigational capability.

It must also be pointed out that the M.V. Kalvik was designed as an icebreaking anchor handling tug and offshore supply vessel for use in the southern Beaufort Sea. All aspects of its design meet, and in some cases, substantially exceed, the requirements of the Canadian ASPPR Arctic Class Four. Nonetheless, it was not designed to operate routinely in the severe multi-year ice conditions encountered in these trials.

Its typical icebreaking mission profile calls for it to transit thick (i.e., up to 2 meters), heavily ridged (ridges up to 10 meters in thickness), first year ice and to be capable of breaking up individual large second year or multi-year floes that may approach the BeauDril drilling sites. It is not normally called upon to navigate long distances in thick multi-year ice which is generally acknowledged to constitute the most severe condition for ice navigation and the one most likely to cause damage to shipping.

The propellers, while heavily ice strengthened, are unducted and are exposed to contact with massive pieces of ice, particularly from below, as ice passing under the hull from the bow can move along the underside of the shaft boss and must then pass through the lower third of the propeller disk before escaping astern. Individual multi-year ice blocks having a mass of more than 100 tonnes were observed on a number of occasions during these tests to have passed through the propellers in just this way.

While the ice conditions encountered in these tests are very nearly the most severe that could be accessible to a ship of this size in the Canadian Arctic, it cannot be concluded that the ice loading of the propellers observed in these tests reached the extreme upper limit possible for such operations. Indeed, there is strong evidence to suggest that randomly distributed factors such as the relative geometry of ice piece, the propeller and the surrounding hull play an important role in determining the magnitude and direction of loading of the propulsion system elements. It is quite likely that with a longer period of observation in similar ice conditions, still higher loads would eventually be recorded than those that have been obtained in the course of this work.

Overall Conclusions

1. The measurements obtained during the tests have shown that all of the propulsion train components worked well within their design limits, except for the propeller blades and the stern tube seal.

2. The maximum blade force calculated was 2.3 MN (235 tonnes) (event Test 28). A force of this magnitude acting at 0.9 radius will yield the blade at 0.6 radius. The shaft movement exceeded the radial of the stern tube seal (1.0 mm) by 1.1 mm during the same event. These responses occurred under the following conditions:

   Heavy Ice Milling by Propeller (Test 28)

   - ahead propeller pitch was decreased from 11 to 2 degrees
   - rudder moved from 4 degrees port to 5 degrees starboard
   - low shaft torque (<500 kNm)
   - shaft thrust varied from 1.0 MN (102 tonnes) ahead to 2.2 MN (224 tonnes) astern.

   High loading on the bearings also occurred during this test.

3. Severe propeller, shafting and bearing loads as well as steering gear vibrations occur under the following condition:

   Ice Wedged between Rudder and Propeller (Test 09)

   - full ahead propeller pitch
   - rudder moved from 18 degrees to 35 degrees starboard
   - high shaft torque (820 kNm)
   - ahead shaft thrust varied from 1 to 2.2 MN (102 to 224 tonnes).

4. The primary mode of response of the shafting is in bending. A bending wave is produced on the shaft by high blade ice impacts loads. Both the axial and in-plane component of this load cause this bending.

5. In the forward and aft stern tube bearings the maximum dynamic load calculated was 1.1 MN (112 tonnes) and 2.2 MN (224 tonnes) respectively. These loads were applied at the ends of each bearing, while the centre of the bearings do not experience high forces.

6. The peak dynamic forces on each bearing do not occur at the same time. These peak forces propagate inboard from the propeller along the shaft.

7. The bending of the hull girder of the M.V. Kalvik during the ramming of heavy ice ridges does not induce significant loading on the shafting and bearings.

8. Based upon the results obtained from this work the following parameters were determined as being essential in the dynamic modeling of icebreaker propulsion systems:

- Location and distance between each bearing
- Inertia and stiffness of shafting system (torsional, axial, bending)
- Length of each bearing
- Clearance of bearings
- Stiffness of bearing materials
- Damping coefficients
- Propeller blade stiffness
- Stern geometry
- Propeller pitch and shaft speed
- ship speed
- added mass of propeller disk
- Stiffness of support structure of bearings

Static Alignment

1. The measured alignment of the starboard shaft line of the M.V. Kalvik conforms well to the Lloyd's recommended alignment condition.

2. The forward flywheel bearing (Frame 55) is the highest loaded intermediate bearing at 0.125 MN (12.7 tonnes). Maximum continuous design load is 0.32 MN (32.6 tonnes). This bearing has been observed to run hot.

Steering Gear Loads

1. Maximum rudder stock torque measured was 1.201 MNm which is 4.6 times the maximum open water torque with a rise time of 0.2 seconds. The vessel was going astern and the rudder angle was 4.5 degrees to starboard. Permanent twisting of the rudder stock will occur at a torque of 3.0 MNm.

2. Rudder stock torques of 0.50 to 0.90 MNm with a rise time of 0.1 second can be caused by ice being wedged between the propeller and the rudder.

Stern Tube Bearing Loads

1. Summary Table

	FORWARD BEARING	AFT BEARING
Max. Local Pressure Measured	5.0 MPa (725 psi)	7.0 MPa (1000 psi)
Max. Estimated Local Pressure	5.0 Mpa (725 psi)	8.0 MPa (1160 psi)
Max. Compression of bearing	2.5 mm (0.1 in.)	4.0 mm (0.17 in.)
Max. Vertical Reaction	0.6 - 1.0 MN (61-102 tonnes)	1.5 - 2.0 MN (153 - 204 tonnes)
Max. Transverse Reaction	0.6 - 1.0 MN (61-102 tonnes)	1.1 - 1.6 MN (112-163 tonnes)
Max. Magnitude of Reaction	0.7 - 1.1 MN (71-112 tonnes)	1.6 - 2.2 MN (163-224 tonnes)
Range of Resultant Angle	0 +/- 60 degrees	0 +/- 90 degrees

2. The most severe reactions of the bearing were recorded when the block of ice was inboard of and below the propeller hub.

3. Approximately 60% of the aft stern tube bearing length is loaded during the maximum loading.

4. The location of the maximum reaction is at the aft end of the bearing and the minimum is approximately 2 m forward of the aft end. The maximum reaction at the forward end of aft stern tube bearing is 50-75% of the maximum at the aft end of the bearing.

Intermediate Bearing Loads

1. Maximum vertical and transverse load measured was 240 kN (24 tonnes) and 170 kN (17 tonnes) respectively. These loads occurred on the aft intermediate bearing. The vessel was going slow ahead and severe ice milling occurred.

2. The maximum vertical and transverse load variation measured was +130 to -230 kN (+13 to -23 tonnes) and +/-(port/stbd.) 170 kN (+/- 17 tonnes) respectively. These loads occurred on the aft intermediate bearing and had a rise time of approximately 0.1 seconds. The vessel was going slow ahead and severe ice milling occurred.

3. The aft and the forward flywheel bearing load variation were approximately 1/4 and 1/9 the load variation of the aft intermediate bearing respectively.

Shaft Torque, Thrust and Bending

1. The maximum thrust variation measured was 1.4 MN ahead to 2.2 MN astern with a rise time of 0.05 seconds and a frequency of approximately 8.7 Hz (blade rate). The vessel was going slow ahead and severe ice milling occurred.

2. The maximum torque variation measured was 300 kNm with a rise time of 0.1 seconds and a frequency of approximately 4.0 Hz. The vessel was going slow ahead and severe ice milling occurred.

3. The shaft bending stress increased by approximately 20% from open water conditions during heavy ice milling.

4. Maximum ahead shaft thrust measured = 2.15 MN (219 tonnes)
5. Maximum astern shaft thrust measured = 2.20 MN (224 tonnes)
6. Maximum shaft torque measured = 820. kNm (836 tonne m)
7. Maximum shaft bending stress measured = 11. MPa

Shaft Movement

1. Extreme shaft movements occur in an ice milling condition with low propeller pitch angles (low torque) and when ice is wedged between the centreline of the vessel and the propeller.

2. Shaft accelerations of up to -5.5 m/sec^2 (0.56 g's) in the vertical direction and -6.5 m/sec^2 (-0.66 g's) (to starboard) in the transverse direction were measured at the stern tube seal during ice milling.

3. Shaft displacements as high as 2.3 mm (0.091 inches) in the vertical direction and 1.9 mm (0.075 inches) (to starboard) in the transverse direction were measured at the stern tube seal during ice milling.

4. The predominant motion of the shaft was in the transverse direction (port to stbd.)

Gear Case

1. The maximum strain difference between the gear case walls was 32 µstrain. This corresponds to a maximum misalignment of 0.0022 degrees which is insignificant.

2. The maximum measured stresses on the gear case due to the loads transmitted through the shaftline are insignificant.

3. The aft gear case responds in a quasi-static fashion for torque excitation and in a vibratory fashion to thrust excitation.

Vibrations

1. Ice milling induces vibrations with structural vertical accelerations as high as 12 m/sec^2 (1.2 g's) near the stern tube seal.

2. The structural vibrations are limited to the local area around the stern tube seal. The accelerations measured in the port stern tube seal and the bow were reduced by a factor of 9.6 and 23 respectively from those at the starboard stern tube seal.

3. The shaft acceleration (as measured by the proximity probes) was approximately 50% less than the structural accelerations measured.

4. The peak structural acceleration measured occurred at approximately the same time as the peak aft intermediate bearing load.

Hull Bending

1. Ramming does not have any significant effect on the shaft line loads especially when compared with ice milling loads.

2. The stern of the ship has not been accelerated during the most severe ram and inertial loads have not been generated in the shaft line.

3. Shaft motions, bending and bearing loads during the ramming did not change from the open water values when ramming ridges.

Gyroscopic Effect of Flywheel

1. The maximum gyroscopic force is estimated at 2.0 kN which is very small in comparison with the static bearing load of approximately 154 kN.

Propeller Blade Forces

1. Maximum longitudinal ice load on one blade is estimated at 2.3 MN (235 tonnes). Under this load, the onset of yielding of the blade would occur at 0.6 radius.

2. The maximum transverse load on one blade was estimated at 0.96 MN (96 tonnes).

3. Approximately 2/3 of the blade is immersed in ice during the milling process, therefore the depth of cut is approximately 0.93 m.

4. The angle of sweep during milling is approximately 100 degrees.

9 RECOMMENDATIONS

Recommendations Affecting Design Practice for Ice Class Propulsion.

The measurements made in this study indicate that yielding of the Kalvik's existing propeller blades will be a recurring problem when operating in heavy ice conditions similar to those encountered in these tests. This suggests that it would be of value to investigate the economic feasibility and the consequences for the pyramidal design integrity of such a propeller system of substituting a material having a similar ultimate strength but possessing a yield strength which is a higher fraction of the ultimate strength.

If it could be shown that the correct strength relationship amongst system components could be preserved and the probability of ultimate failure not increased, this could have the potential to significantly improve propeller blade reliability in heavy ice service. Such an investigation is recommended and should be of interest to a number of both private and government operators of ice class shipping.

Recommendations Affecting the Operation of the M.V. Kalvik

It is recommended that the measured transverse movements of the propeller shafting at the stern tube seal be discussed with the seal manufacturer with a view to establishing the relative importance and expected maintenance consequences of such movements. It may be useful to consider fitting a different type of seal, having a greater tolerance to such transverse movement if rapid degradation of the performance of this seal in icebreaking service is observed.

It is observed that in this installation high impact loads can be coupled from the propeller disk to the rudder blade by intervening ice masses when the rudder is hard over. Some means of alerting the operator to this condition or a standard operating procedure relating to the use of the rudder in severe ice conditions to minimize the exposure of the steering gear to potentially destructive fatigue loads is recommended.

If the vessel should be operated in ice service in a condition conducive to rapid wear of the sea water lubricated bearings, such as in silty water, the effect of bearing wear-down on ice impact induced transverse shaft movements and reactions at the aftmost pedestal bearing should be closely monitored.

Recommendations Relating to Modelling of Ice Loading of Propulsion

It is recommended that the information obtained in this investigation, together with other existing sources of related propulsion system response data for ice operations, be used as the basis for specification of a generalized modelling technique that will:

a) Generate representative propeller-blade ice force magnitude and direction time histories based upon a description of the impact geometry, the dynamic response of the propeller blade and the strength, mass and motion constraints upon the ice. The appropriate dynamic strength and elastic properties to model sea ice would be determined empirically to reproduce the available full scale data.

b) Predict torque, thrust and bearing reactions throughout the shafting system for arbitrary user-specified shafting and bearing arrangements and in response to an arbitrary input time history for the load vector acting on the propeller disk.

Such a model could be used to investigate the effect of varying the number, location and length of the shaft bearings upon the bearing reactions and shaft movement amplitudes in ice operations. It is recommended that the model also be developed to be capable of modelling the effect of varying the bearing clearances and the static and dynamic alignment condition of the shaft bearings.

The torque response modelling capability would be used to investigate the effect of alternative distributions of system rotational inertia on torsional reactions at critical system elements such as clutches, gears or prime movers.

The model should be implemented as a suite of interactive, menu driven computer programs capable of being run on standard technical engineering work stations currently in use in the marine design industry. The use of graphics for displaying both input and output information should be emphasized to permit easy interpretation and validation of these quantities.

For many elements of the model standard, well proven computer routines are available. Wherever practical such routines should be incorporated, integrating them to share a common user interface, file structure and input/output system. These routines would be supplemented with new code to handle aspects of the modelling such as generation of the propeller-ice load for which existing code does not exist.

Finally, the modelling system should be equipped to store and display a number of representative shafting response cases measured at full scale, as well as its own internally generated prediction of these responses for the same initial conditions. In this way the system software can be used not only as a means of investigating new propulsion designs, but will also serve as a tool for accessing the growing data base of actual full scale data.

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M.V. KALVIK
PROPULSION SYSTEM FULL SCALE TESTS

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Volume 2 - Appendices

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Un sommaire en français de ce document est inclus avant la table des matières.

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PROJECT TEAM

This program has been conducted with the support and on behalf of three contributory participants: the Transportation Development Centre of Transport Canada, an Agency of the Canadian Federal Government located in Montreal, Quebec, BeauDril Limited of Calgary, Alberta, and the Johnson Rubber Company of Middlefield, Ohio, U.S.A.

Arctec Canada Limited acted as the principal contractor to the project with overall responsibility for the design and installation of the instrumentation, the collection of the data in the field, and the subsequent analysis and reporting of the results.

Arctic Research and Development Ltd. acted as a subcontractor to Arctec Canada Limited, assisting with certain aspects of the experimental design and calibration and with analysis and reporting of certain aspects of the data.

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17. Abstract

Full scale propulsion tests were conducted on the Class 4 Icebreaker M.V. Kalvik. The program included complete dynamic measurements of the starboard shafting system response, hull bending stresses, and structural accelerations during icebreaking operations. Unique instrumentation was developed to measure the reactions in each of the two salt-water lubricated rubber stern tube bearings.

The instrumentation was installed in August 1986. Following the drydocking, the M.V. Kalvik proceeded to Resolute Bay, N.W.T., through the Prince of Wales Strait and Viscount Melville Sound. Extensive high speed recordings of the total shafting system response to severe ice milling were made during some eight days of transitting and maneuvering in heavy second-year and multi-year ice.

The program resulted in a detailed description of the response of the shafting and bearings to dynamic ice loads, as well as the determination of the magnitude of forces on propulsion system components. The loads measured on the propulsion system of this vessel are among the highest recorded, and were under some of the most severe ice navigation conditions encountered in the Canadian Arctic.

It is concluded that all of the propulsion train components operated within their design limits, except for the propeller blades and the stern tube seal. An extensive data base suitable to support the development of a modelling methodology for ice class shafting systems was obtained.

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Ship, icebreaker, Kalvik, propulsion, propellers, rudders, shafting, stern tube bearing, ice load, resistance, Arctic tests

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Volume I - Rapport principal
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Pierre Sémery

17. Résumé

Ce rapport concerne les essais de propulsion en vraie grandeur effectués à bord du brise-glace de classe 4, N.M. Kalvik, dans le cadre d'une campagne de mesures complètes des contraintes dynamiques sur la ligne d'arbres tribord, des contraintes en flexion de la coque et des accélérations lors des opérations dans la glace. Une chaîne de mesures unique en son genre a été mise au point pour mesurer les contraintes sur chacun des deux paliers d'étambot en caoutchouc, lubrifiés à l'eau de mer.

Après la mise en place de la chaîne de mesures, en août 1986, le brise-glace a quitté Tuktoyaktuk à destination de Resolute, T.-N.-O., via les détroits du Prince-de-Galles et du Vicomte-Melville. Durant les quelque huit jours de marche et de manoeuvre dans des glaces de deux et plusieurs années, des enregistrements à haute vitesse complets des efforts d'ensemble exercés sur la ligne d'arbres ont été effectués.

Cette campagne a débouché sur une description détaillée de la tenue de la ligne d'arbres et des paliers aux charges dynamiques dues à la glace, ainsi que sur la détermination de l'amplitude des forces agissant sur chacun des éléments du système propulsif. Les charges mesurées ont été parmi les plus élevées jamais enregistrées, les conditions de navigation ayant été parmi les plus rigoureuses jamais rencontrées dans l'Arctique.

Il a été déterminé qu'aucun des éléments du système propulsif n'a été sollicité au-delà de sa résistance nominale, à l'exception des pales de l'hélice et de l'étanchéité avant du tube d'étambot.

18. Mots-clés
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LIST OF APPENDICES

APPENDIX A - Contractual Agreements and Statement of Work
APPENDIX B - Laboratory Investigations
APPENDIX C - Static Alignment Measurements and Calculations
APPENDIX D - Field Notes and Calibration Calculations
APPENDIX E - Photographs
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APPENDIX G - Description of Data Products

APPENDIX A

Contractual Agreements and Statement of Work

PREFACE TO AGREEMENT

Following is a Confidentiality Agreement among all Participants in a Project described as "Propulsion System Full Scale Tests and Analysis on M.V. Kalvik", being undertaken by Arctec Canada Limited for Transport Canada (hereinafter called the Project).

The participants in the Project are: Transport Canada (TC); BeauDril Limited (BL); Johnson Rubber Company (JRC) and Arctec Canada Limited (ACL).

This agreement deals only with the issue of confidentiality with regard to the Project, and other matters related to the exact nature of the work to be performed and compensation for such work is the subject of other agreements between the relevant parties.

CONFIDENTIALITY AGREEMENT

AGREEMENT AMONG AND BETWEEN:

ARCTEC CANADA LIMITED (hereinafter referred to as ACL)
A Corporation duly incorporated under laws of Canada.

BeauDril LIMITED (hereinafter referred to as BL)
A Corporation duly incorporated under laws of Canada.

THE JOHNSON RUBBER COMPANY (hereinafter referred to as JRC)
A subsidiary of Duramax Inc. , a Corporation duly incorporated
under laws of Ohio.

and

TRANSPORT CANADA (hereinafter referred to as TC)
A department of the Canadian government.

WHEREAS ACL intends to engage the services of BL and JRC in connection with a Project for TC described as:

"PROPULSION SYSTEM FULL SCALE TESTS AND ANALYSIS ON M.V. KALVIK"

It is agreed as follows:

GOVERNING LAW

This agreement shall be construed in accordance with the laws of the Province of Alberta. The parties here to agree to submit to the jurisdiction of the Province of Alberta in any actions related to this agreement.

PROJECT PRODUCT

As used herein the term PROJECT PRODUCT shall mean all information, data, results, etc., which the parties directly or indirectly, acquire through the conduct of the Project except information which, prior to the commencement of the Project is lawfully in the public domain.

PROPERTY OF PROJECT PRODUCT/CONFIDENTIALITY

All drawings, documents, engineering and process data, design calculations, and materials prepared or provided as a result of performing the Project (the Product) shall be the property of TC. TC agrees that BL and JRC shall have full access to and internal use of the Product of the Project in such form (data, reports, information) as they are produced. BL, JRC and TC agree that for a period of two (2) years from the date of this agreement, they all shall refrain from disclosing and will use their normal precautions to prevent their employees from disclosing the said confidential information, subject to this agreement.

Publication or sale of the data and information or part thereof within the period of the Confidentiality Agreement would only be permitted by prior mutual agreement of all three parties.

TC, BL and JRC may release the results to their agents or contractors, provided that such agents or contractors agree to a Covenant of Confidentiality the same as herein and also provided that such data will be used solely for studies or projects for the account of TC, BL or JRC.

TC, BL and JRC may not disclose the terms of this specific agreement or make use of the names of the parties or personnel without the prior approval of all three parties.

ACL agree that the Project Product and/or any other Proprietary Information they obtain through involvement in the Project (that was not previously in the public domain) shall be treated as proprietary. ACL agree that they have no rights or interest in the Project Product or related proprietary information and thus shall not publish or disclose said information without the prior approval of BL, TC, and JRC.

N. E. Rudlock
TRANSPORT CANADA

6/01/87
DATE

Robert E Rushton
BeauDril LIMITED

86-12-03
DATE

Byron J Fulle
JOHNSON RUBBER CORPORATION

8/15/86
DATE

MH Edgecombe V.P.
ARCTEC CANADA LIMITED

86/08/12
DATE

ARCTEC CANADA LIMITED

AGREEMENT REGARDING USE OF M.V. KALVIK

By and Between

Arctec Canada Limited

(hereinafter called ACL)

and

BeauDril Limited

(hereinafter called BL)

whereas

ACL requires access to BL's vessel the "M.V. Kalvik" during both its forthcoming docking and subsequent ice operations in the balance of the 1986 operating season for the conduct of a Project for Transport Canada called "Propulsion System Full Scale Tests and Analysis on M.V. Kalvik" (hereinafter called the Project).

BL agrees:

To provide access to the vessel the M.V. Kalvik on an opportunity basis, (as described in Exhibit A) to ACL and its agents for the conduct of the Project.

ACL agrees:

1) To provide a copy of the information, data and conclusions gathered through the conduct of the project to BL in accordance with the terms and conditions of a separate Confidentiality Agreement.

2) ACL represents warrants and agrees that it has the required skills and capacity to perform the Project and shall perform such in a professional manner using qualified and competent personnel.

3) Any proposed modifications necessary to the vessel for the conduct of the Project will be approved by Lloyds Register and BL before being undertaken.

4) To perform the project in character, sequence and timing so as to co-ordinate with the availability of the vessel.

ACL & BL agree:

1) To comply and secure compliance by its subcontractors with all applicable laws whether Federal, Provincial or Municipal and the rules and regulations of regulatory bodies acting thereunder in connection with the Project.

2) To maintain and keep in force during the term of the Project the following minimum insurance.

a) Employer's Liability Insurance:

Covering each employee engaged in the Project hereunder to the extent of $200,000.00 where such employee is not covered by Workers Compensation as required in the jurisdiction in which the Project is being performed.

b) Automobile Liability Insurance:

Covering all vehicles used in connection with this Agreement. In respect of such non-company owned vehicles they shall maintain and keep in force non-owned automobile liability insurance protecting their liability, including that assumed under this Agreement. The limits of insurance under this provision shall not be less than:

Bodily Injury (including passenger hazard) and Property Damage; one million dollars inclusive any one accident or equivalent limits.

c) Production Property Insurance:

Covering all tools, machinery, equipment, spare parts and materials used in conjunction with the Project.

d) Comprehensive General Liability Insurance:

Covering operations in connection with this Agreement (other than the operation of automobiles and aircraft), including employer's liability, ACL's and BL's contingent liability with respect to the operations of their subcontractors, and contractual liability as respects liability assumed by ACL and BL's under this Agreement. The limits of such insurance shall be not less than Bodily Injury and Property Damage One Million Dollars inclusive any one accident or equivalent limits.

e) Insurance Required by Law:

ACL and BL shall provide at their own expense any other insurance which they are required by law to provide.

3) To indemnify each other and their affiliates against all actions, proceedings, claims, demands, losses, costs, damages, and expenses whatsoever which may be brought against or suffered by them or their affiliates or which they may sustain, pay or incur; as a result of or in connection with the performance, purported performance or non-performance of this Agreement, or of the services hereunder by the other and whether the same results from or in connection with the use by ACL or BL of any machinery, tools or equipment belonging to the other and their affiliates, but excluding any such actions, proceedings, claims, demands, losses, costs, damages, and expenses to the extent that they are sustained, paid or incurred by reason of or are otherwise attributable to the negligence or willful acts or omissions of ACL or BL themselves or affiliates, their servants, agents, employees, or their other subcontractors.

This agreement in its' entirety is subject to ACL receiving a contract from Transport Canada to finance the work as described in Exhibit A.

This agreement is also subject to the completion of a confidentiality agreement between and among Transport Canada, BeauDril Limited, Johnson Rubber Corporation, ACL, and Arctic Research and Development Ltd.

Dated this 16TH day of JULY 1986

VICE PRESIDENT
ARCTEC CANADA LIMITED

Robert K Rushton Superintendent Marine Engineering
BeauDril LIMITED

EXHIBIT A

SCOPE OF WORK

BeauDril Limited (BL) will make available, free of charge, the vessel "M.V. Kalvik" on a non-interference basis for trials on the propulsion system.

This vessel is being dry docked and work will be performed on the shaft and bearings. Access to the vessel will be provided in order to instrument the shaft and bearings, and no costs will be incurred by Arctec Canada or Transport Canada for the docking, nor for work on the shaft other than that for which Arctec Canada is contracted by Transport Canada.

BL will provide accommodation onboard the vessel at no cost during the conduct of the trials to a maximum of four persons.

BL will provide transportation to the vessels from Edmonton at no cost, on an as space available basis.

BL agrees to cooperate in the operation of the vessel to the greatest degree possible subject to local operational requirements, and to execute specific ship operations of interest if these can be accommodated and cause no interference with operations.

BL also agrees to provide the services of qualified engineers and technical staff to participate in the tests and the analysis of the data as required.

BL will not be responsible for the maintenance of the instrumentation installed by ACL or the results obtained.

In return, BL will be provided with the data and results from the tests under conditions of confidentiality set out in a separate confidentiality agreement.

AGREEMENT REGARDING PROVISION OF BEARINGS AND RELATED SERVICES ON M.V. KALVIK

By and Between

ARCTEC CANADA LIMITED
(hereinafter called ACL)

and

JOHNSON RUBBER COMPANY
(hereinafter called JRC)

whereas

ACL requires the services of JRC in the conduct of a Project for Transport Canada called "Propulsion System Full Scale Tests and Analysis on M.V. Kalvik", (hereinafter called the Project).

JRC agrees:

To provide bearings and related services on the M.V. Kalvik (as described in Exhibit A) in connection with the Project for Transport Canada being performed by ACL.

ACL agrees:

1) To provide a copy of the information, data and conclusions gathered through the conduct of the project to JRC in accordance with the terms of a separate Confidentiality Agreement.

ACL & JRC agree:

1) To comply and secure compliance by its subcontractors with all applicable laws whether Federal, Provincial or Municipal and the rules and regulations of regulatory bodies acting thereunder in connection with the Project.

2) To maintain and keep in force during the term of the Project the following minimum insurance.

a) Employer's Liability Insurance:

Covering each employee engaged in the Project hereunder to the extent of $200,000.00 where such employee is not covered by Workers Compensation as required in the jurisdiction in which the Project is being performed.

b) Automobile Liability Insurance:

Covering all vehicles used in connection with this Agreement. In respect of such non-company owned vehicles they shall maintain and keep in force non-owned automobile liability insurance protecting their liability, including that assumed under this Agreement. The limits of insurance under this provision shall not be less than:

Bodily Injury (including passenger hazard) and Property Damage; one million dollars inclusive any one accident or equivalent limits.

c) Production Property Insurance:

Covering all tools, machinery, equipment, spare parts and materials used in conjunction with the Project.

d) Comprehensive General Liability Insurance:

Covering operations in connection with this Agreement (other than the operation of automobiles and aircraft), including employer's liability, ACL's and JRC's contingent liability with respect to the operations of their subcontractors, and contractual liability as respects liability assumed by ACL and JRC's under this Agreement. The limits of such insurance shall be not less than Bodily Injury and Property Damage One Million Dollars inclusive any one accident or equivalent limits.

e) Insurance Required by Law:

ACL and JRC shall provide at their own expense any other insurance which they are required by law to provide.

3) To indemnify each other and their affiliates against all actions, proceedings, claims, demands, losses, costs, damages, and expenses whatsoever which may be brought against or suffered by them or their affiliates or which they may sustain, pay or incur; as a result of or in connection with the performance, purported performance or non-performance of this Agreement, or of the services hereunder by the other and whether the same results from or in connection with the use by ACL or JRC of any machinery, tools or equipment belonging to the other and their affiliates, but excluding any such actions, proceedings, claims, demands, losses, costs, damages, and expenses to the extent that they are sustained, paid or incurred by reason of or are otherwise attributable to the negligence or willful acts or omissions of ACL or JRC themselves or affiliates, their servants, agents, employees, or their other subcontractors.

This agreement in its' entirety is subject to ACL receiving a contract from Transport Canada to finance the work as described in Exhibit A.

Dated this 8 day of August 1986.

MH Edgecombe VP

ARCTEC CANADA LIMITED

JOHNSON RUBBER COMPANY

EXHIBIT A

SCOPE OF WORK

Johnson Rubber Company (JRC) agrees to provide the following services free of charge in connection with the Project:

- Provide assistance to ACL in the design and installation of sensors to measure the temperature and pressure in the bearing staves of the stern and forward shaft bearings.
- To manufacture and machine bearing staves to accommodate the instrumentation, including wiring, in such a way as to minimize the effect of the instrumentation and wiring on the bearing.
- To provide technical personnel for the installation of the instrumented bearing while the ship is dry-docked in the Arctic base.
- To provide all normal warranty conditions applying to the bearings to BeauDril Limited.

In return JRC will be provided with the data and results of the Project under conditions of confidentiality set out in a separate Confidentiality Agreement.

APPENDIX A - WORK STATEMENT

The completion status of each task is as follows:

Task Description	Percent Complete
Task 1 - Planning and System Design	100
Task 2 - Software Development	100
Task 3 - Instrumentation Design/Installation and Equipment Procurement	100
Task 4 - Full Scale Tests	100
Task 5 - Analysis of Full Scale Data	100
Task 6 - Prepare and Present Final Report	95

APPENDIX "A"

TRANSPORTATION DEVELOPMENT CENTRE

ICE INTERFERENCE IN PROPULSION SHAFT DYNAMICS

WORK STATEMENT

1. INTRODUCTION

It is well established that the weakest point in any ship is the stern bearing and the propeller. What is true for open water ships is still more critical for icebreakers spending their active life in ice infested waters. There are for these particular vessels still a lot to be learned in order to produce safer and more reliable design for future ships travelling in this sort of environment.

We have in this project an opportunity quite unique to be able to test ice interference in the worse conditions as the ship used for this programme has an unprotected propeller and also a rubber compound stern bearing which will permit measurements of fairly large forces due to ice, without excessive risk.

This program of research and development is to be performed on the icebreaker M.V. Kalvik, operated by BeauDril (a subsidiary of Gulf Canada Resources Inc.), in 1986 as part of a joint Industry/Government research effort. The program reflects the outcome of meetings with BeauDril, T.D.C.' Arctic Research and Development Limited, and Arctec Canada Ltd. personnel, in April and May, 1986 and a subsequent proposal made to Transport Canada (June 9, 1986) referred to thereafter as the proposal. Discussions with Johnson Rubber Company also took place.

2. MODAL OBJECTIVE

To develop all aspects of technology required to establish safe and efficient year-round navigation capability in Arctic Waters as required by Canada.

3. MODAL SUB-OBJECTIVE

To advance the state-of-the-art and performance capabilities of marine vehicles used by government or by industry for safe and efficient year-round operations in Canadian Arctic Waters.

4. PROJECT OBJECTIVE

To evaluate the behaviour of all substantial elements included in the propulsion train from propeller to main gear when in ice by first of all determining the effect of ice interaction then establishing sound bases for the design of the next generation of icebreaking vessels.

5. DETAILED STATEMENT OF WORK

Work to be done is generally as stated in the proposal, but tasks outlined in the proposal are detailed or modified as indicated below. Should there be any inconsistency this work statement is to take precedence.

5.1 Task 1 - Planning and System Design

Develop a detailed work plan including activity schedule, project management control and documentation procedures, liaison with sponsoring organizations, budget control and progress reports.

A presentation of the detailed work plan is to be made at TDC Montreal at a mutually convenient date within 2 weeks of its preparation. The plan will be discussed with the scientific authority and review committee and may be modified at that time.

Included in the test plan will be as a minimum:

1. An agreement between the contractor and the owner and operator of the vessel (the agreement is to have been signed in total cognizance of all clauses or requirements of the Statement of Work pertaining to ship availability and operation).
2. An agreement between the contractor and the manufacturer of the stern bearing.
3. A confidentiality agreement not exceeding 2 years between these companies and all participating parties will be acceptable.
4. General Schedule and deployment plan including priorities.
5. Procedures for each test and logistic activities.
6. Personnel assignments and schedules.
7. Definition of instrumentation system.
8. Data analysis procedures and sample data sheets.
9. Outline of final report.

5.2 Task 2 - Software Development

Software for the data acquisition and real time analysis will be developed based on previous experience with other full scale tests. The software will be capable of sampling the sensors continuously at a pre-programmed rate. If a manual trigger is applied, or if an event is detected by the program a "window" of data will be stored on disk or tape.

Software for the post-analysis will be developed based on the results of the preliminary tests and required engineering values. This software will be able to perform statistical and time history analysis of data.

5.3 Task 3 - Instrumentation Design, Procurement and Installation

One shaft system is to be instrumented while only power readings are to be obtained from the other.

It is envisaged that parameters will require to be collected, analysed and reported as in the proposal except as amended below. Any variation regarding the number of those parameters is to be brought to the attention of the Scientific Authority.

The following items from the list on page 7 of the proposal are to be amended to read as follows (amendment is underlined):

Component	Number of Sensors	Description
Shafting	12	Bending 3 Locations (4 equally spaced circumferential)
Stern Tube Bearings - Load	12	Fwd Stern Tube (1 X 12)
Stern Tube Bearings-Temperature	12	Aft Stern Tube
	6	Fwd Stern Tube

The calibration of these sensors will have to be carried out prior to testing and calibration curves are to be produced if any sensors show repetitive constant deviation from direct reading. Any sensor giving random differences are to be eliminated and replaced.

5.4 Task 4 - Full Scale Tests

The test period is to be in September and October 1986, on an opportunity basis as the vessel is under normal operations. The vessel is scheduled to transit to Point Barrow and return; there should be a variety of ice conditions and opportunity for testing.

The data acquisition software is to be capable of detecting events and storing event data automatically. The tests are to consist of a number of controlled ahead and stern manoeuvers in broken and unbroken ice. Instrumentation is to be left on board to collect statistical data on certain key parameters, throughout at least one complete operating season. This data would help in predicting extreme loads and responses which may occur infrequently, and not during dedicated tests.

In addition to instrumentation data collection, a log of ship operating status is to be kept at all times (ice conditions, environmental conditions, ship status, etc).

Photographic documentation of ice conditions will be collected. An on-ice survey is to be conducted.

During the tests, near real time analysis of data to be performed, to enable personnel to ascertain the status and validity of sensor outputs, and to permit re-adjustment of calibration if necessary.

5.5 Task 5 - Analysis of Full Scale Data

The analysis will be required to address as a minimum the following items:

5.5.1 BEARINGS

- Movement of shaft in stern tube bearings in open water.
- Movement of shaft in stern tube bearings during ice-propeller interaction.
- Distribution of load in stern tube bearings in open water.
- Distribution of load in stern tube bearings during ice-propeller interaction.
- Distribution of temperature in stern tube bearings in open water.
- Distribution of temperature in stern tube bearings during ice-propeller interaction.
- Flexure of bearing supports in open water conditions.
- Flexure of bearing support during ice-propeller interaction.
- Vibrations in structure around bearings.
- Transverse and vertical load on shaft bearings.

5.5.2 FLYWHEEL

- Reaction of bearings due to gyroscopic effect when ship rises up on ridges. Record of ship speed and of ship's final attitude to be recorded.

5.5.3 PROPELLER

- The forces on the propeller blades are to be calculated from shaft thrust and torque readings, using the dynamic model described in 5.5.8.

5.5.4 THRUST

- Effect on bearing load due to thrust variations in open water and ice conditions.

- Effect on gear case due to thrust variations in open water and ice conditions.

5.5.6 TORQUE

- Variations of torque through propulsion train with power requirements.

- Variations of torque through propulsion train during ice-propeller interaction.

5.5.7 HULL

- Effect of hull responses on propulsion system under normal conditions, during ice-propeller interaction, and when ship is climbing over or ramming ridges.

- The data is to be analysed on the vessel in near real time in a preliminary manner. Further analysis and interpretation of data is to be conducted after the test period. Additional analysis to be done as required and specified after and during the full scale tests.
  N.B. Provisions are to be made for flexibility in the analysis of unplanned but important data which may be acquired in the course of the trial.

5.5.8 ANALYTICAL MODELLING

Dynamic Shaft and Propeller Models are to be developed for predicting propeller blade loads, from shaft torque and thrust measurements, based on the models developed for Transport Canada from the M.V. Robert Lemeur Propeller Blade Project. The models are to take into account the stiffness/resilience of the thrust bearing and other significant supports.

The full scale data is to be used to develop the following analytical models of the propulsion train for future projects:

1. Develop Shafting Models for estimating transient response in torque, bending and thrust on the shafting system.

2. Develop Bearing Models for determining bearing loads, pressure distribution, and temperature response.

3. Develop Alignment Models for determing static response and transient reponse due to ice loading.

Software will be developed and documented for model development.

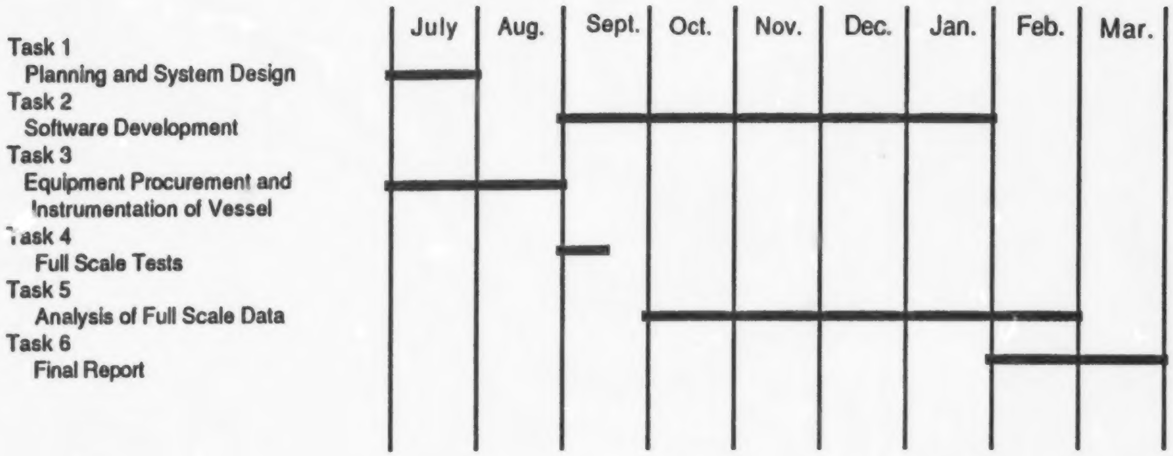
5.6 Task 6 - Prepare and Present Final Report

✓

At the conclusion of the project Arctec Canada Ltd. is to prepare a final report consisting of an Executive Summary, Main Report and appendices documenting the entire study and presenting conclusions and recommendations.

Six (6) copies of a draft report are to be submitted to TDC. Some of these reports may be distributed by TDC to participants for review and comments.

Upon receipt of comments a discussion on the different matters raised will take place in order to reach a concensus and settle those matters which will then be included in the final report at the discretion of the Scientific Authority. Upon submission of the revised final report, a final presentation of the study results is to be made at TDC.



WORK SCHEDULE

APPENDIX B

Laboratory Investigations

2452

M.V. KALVIK INSTRUMENTATION

TRIP REPORT

STRAIN GAUGE AND THERMOCOUPLE INSTALLATION
JOHNSON RUBBER COMPANY
DURAMAX MARINE PRODUCTS
MIDDLEFIELD, OHIO
JULY 20 - 25, 1986

SUBMITTED TO

SUBMITTED BY

ARCTEC CANADA LIMITED
16, 6325 11 STREET S.E.
CALGARY, ALBERTA
T2H 2L6

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2. NOTES FOR INSTALLATION IN VESSEL

3. FIELD NOTES

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   5 of 6 Aft-Aft Strain Gauges - Data Summary
   6 of 6 Thermocouple installation

APPENDIX A - STRAIN GAUGE APPLICATIONS NOTES:

   i) M Bond AE-10 Adhesive
   ii) M Coat J Protective Coatings
   iii) Strain Gauge Engineering Data Sheets (8 pages)

PROJECT NO. 2452
M. V. KALVIK INSTRUMENTATION

TRIP REPORT:
Strain Gauge and Thermocouple Installation
Johnson Rubber Company
Middlefield, Ohio
July 20 - 25, 1986

PERSONNEL: Ron Ritch, Arctec Canada Ltd.
Jim Gillespie, CANDOR

PURPOSE: To install and encapsulate 33 strain gauges with shielded lead wires and 18 thermocouples with stainless steel sheaths into grooves and wells machined in the back surface of the Forward-Stern, Forward-Aft and Aft-Aft rubber bearing staves of the M.V. Kalvik prior to shipment to the vessel.

TRIP LOG:

86.07.20 Jim Gillespie travelled from Calgary to Toronto 9:50 AM to rendezvous with Ron Ritch and thermocouple supplier at airport. No show of supplier caused missed flight, delayed flight, plane pulled from service in London, Ont., and final arrival at Red Roof Inn, Mentor, Ohio 1:30 AM following day.

86.07.21 Arrived Johnson Rubber Company, Middlefield, Ohio at 10:00 AM. Met with Byron Telle, General Manager of Duramax Marine Division , and Engineers Tom Blackie and Bart Caldwell. Machining of the bearing staves was incomplete and no work could be started at this time. Purchased some supplies locally, set up work area. By late afternoon, some machined pieces were available. Rapid wear of the milling cutter caused surface preparation difficulties- needed jewellers file, 220 grit and 400 grit paper to produce acceptable finish to bond gauges. Installed 4 strain gauges by 8:00 PM.

86.07.22 Start work 9:30 AM. Machinist had produced more finished pieces. Decision is reached to use surface grinding, but leaves ridges and is abandoned. Only solution appears to be changeout of the cutter every 3rd or 4th hole. Cut cables to length; some difficulty with etchant. Problem diagnosed as probably due to storage of etchant at room temperature for extended period of time since potency of fluid is spent after very small wire lengths. Decided to locate fresh supply.
Installed 10 strain gauges; wired 4 strain gauges and tested by 8:00 PM.

86.07.23 Start work 9:00 AM. Ordered additional etchant, completed small leadwire etching and partial jacket etching.
Installed 19 strain gauges by 8:30 PM.

86.07.24 Start work 9:00 AM. Etchant arrived, all cable jackets completed. Machining completed by noon. Wired and tested 29 strain gauges- complete. Installed all thermocouples in drill holes with AE10 epoxy. Finish 10:00 PM.

86.07.25 Start work 9:00 AM. Encapsulated all strain gauges and thermocouples in full wells including approx. 2" of cable along groove with M-Coat J polysulphide. Damaged strain gauge Forward Stern FS1-3 during potting. This well must be resurfaced and the gauge installed in the field. Tested all strain gauges for resistance while potting compound still liquid- all OK but resistance shifts during cure cycle and should be repeated just before

installation for permanent record. Turned completed staves over to Johnson Rubber who will install silicone rubber along remaining length of signal cables commencing 86.07.28. Finish 3:00 PM.
Return flights to Calgary via Toronto. Arrive Calgary 11:00 PM.

2) Notes for Installation in Vessel

a) Before and after installation of bearing staves, measure all strain gauge resistances, including lead wires from red-white and red-black. Compare to original values in field notes to identify damage.

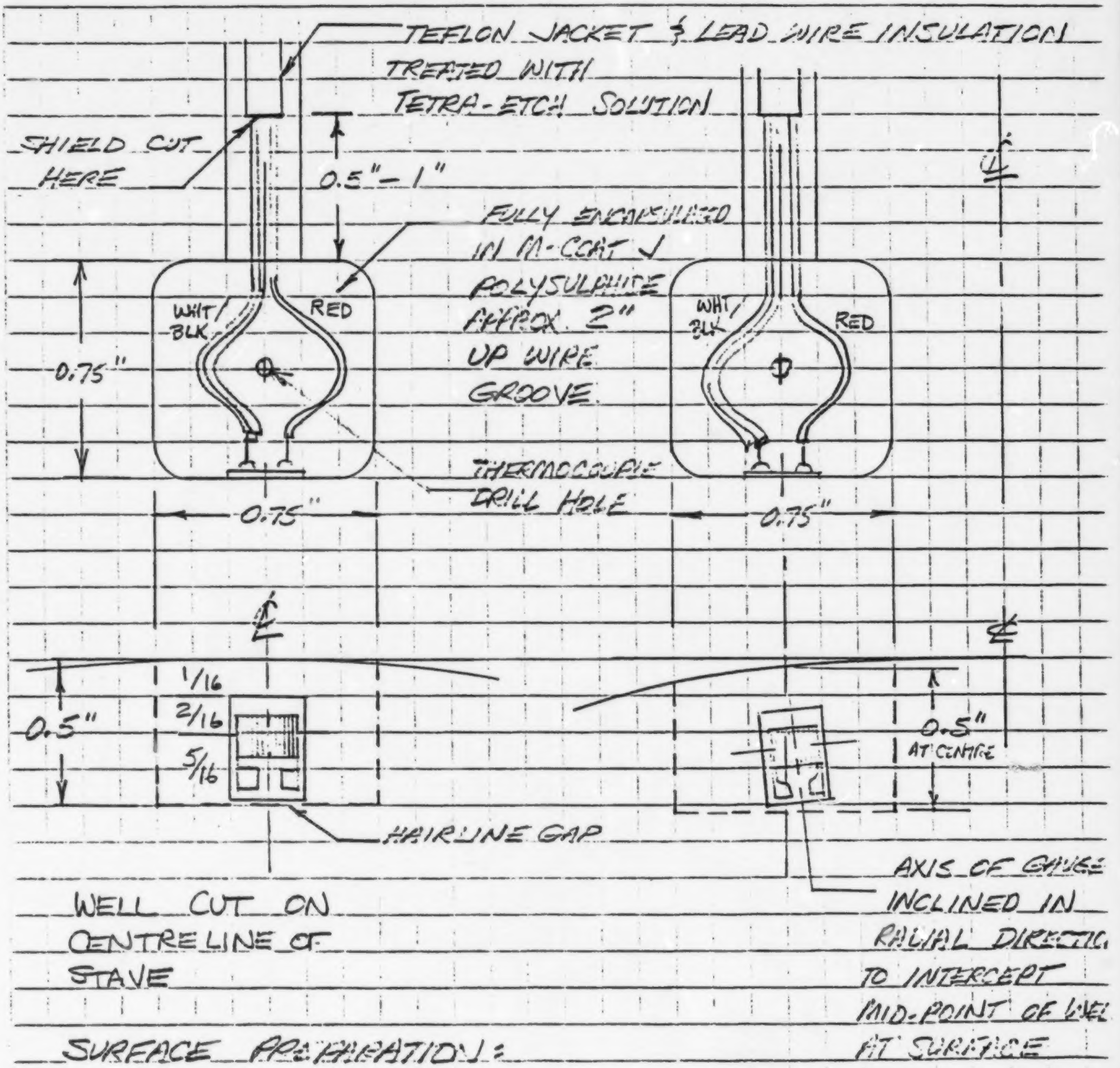
b) Check red, white & black to shield resistance to guarantee no short circuits.

c) Install new forward stern strain gauge in well and pot with M Coat J. Record gauge resistance and gauge plus lead resistances. Identify cable as FS 1-3

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT M.V. KALVIK INSTRUMENTATION
SUBJECT STRAIN GAUGE PLACEMENT IN MACHINED WELL

SHEET 1 OF 6
DATE JULY 21/86
BY JDG
CH'K. BY


TEFLON JACKET & LEAD WIRE INSULATION TREATED WITH TETRA-ETCH SOLUTION
SHIELD CUT HERE
0.5"–1"
FULLY ENCAPSULATED IN M-COAT J POLYSULPHIDE APPROX. 2" UP WIRE GROOVE
WHT/BLK
RED
0.75"
THERMOCOUPLE DRILL HOLE
0.75"
WHT/BLK
RED
0.75"
℄
℄
1/16
2/16
5/16
0.5"
HAIRLINE GAP
℄
0.5" AT CENTRE
AXIS OF GAUGE INCLINED IN RADIAL DIRECTIO
TO INTERCEPT MID-POINT OF WEL AT SURFACE

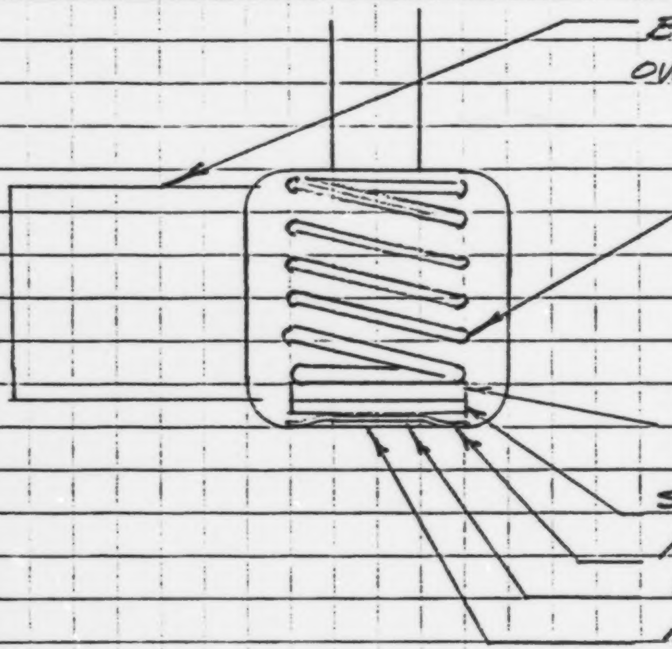
WELL CUT ON CENTRELINE OF STAVE

WELL CUT OFF CENTRELINE OF STAVE

SURFACE PREPARATION:
1) JEWELLER'S FILE
2) 220 GRIT PAPER
3) 400 GRIT PAPER
4) ISOPROPYL ALCOHOL CLEANING – Q TIPS
5) M-PREP NEUTRALIZER 5 FINAL TREATMENT – Q TIPS & STERILE GAUZ
6) AIR DRY + HEAT FROM LAMP

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT M.V. KALVIK INSTRUMENTATION
SUBJECT STRAIN GAUGE CLAMPING
SHEET 2 OF 6
DATE JULY 21/86
BY JDG
CH'K. BY



BLACK ELECTRICIANS TAPE OVER SPRING FOR SAFETY
COMPRESSION SPRING 6 TURNS @ 1/2" DIA. UNCOMPRESSED LENGTH 1", COMPRESSED LENGTH ≅ 5/8"
1/8" ALUMINUM PLATE 1/2" x 3/4"
SILICONE RUBBER PAD
MYLAR TAPE 1/2" WIDE
STRAIN GAUGE
ADHESIVE MICRO-MEASUREMENTS AE-10 EPOXY

ADHESIVE CURE :

AE-10 TWO PART EPOXY.

1) 5 MINUTE MIX RESIN & HARDENER
2) THIN FILM APPLICATION
3) MINIMUM 6 HRS @ 75 °F NECESSARY, ACTUAL CURE OVERNIGHT ≥ 12 HRS BEFORE SOLDERING

ARCTEC CANADA LIMITED

ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452

PROJECT M.V. KALVIK INSTRUMENTATION

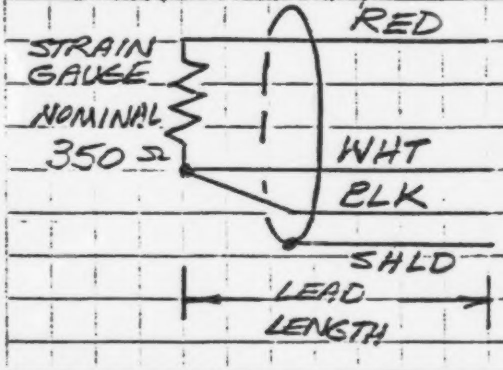
SUBJECT FORWARD-STERN STRAIN GAUGES DATA SUMMARY

SHEET 3 OF 6

DATE JULY 22/86

BY JDG

CH'K. BY



STRAIN GAUGES: MICRO-MEASUREMENTS CEA-06-125UW-350

LEAD WIRE: THERMAX 26 GAUGE STRANDED TEFLON JACKET & INSULATION 3 CONDUCTOR PLUS SHIELD

SOLDER: KESTER SN63 WITH ANTIMONY! (361°)

GAUGE NO: (CABLE ID)	DATE	LEAD LENGTH	GAUGE RESISTANCE (NO LEADS)	OVERALL RESISTANCE (WITH LEADS)		GROUND CHECK (NO SHORT TO SHIELD)
				RED-WHT	RED-BLK	
FS1 - 1	86.07.24	12 m	350 Ω	353 Ω	353 Ω	✓
FS1 - 2	86.07.24	12 m	350	353	353	✓
FS1 - 3	86.07.24	12 m	349	353	353	✓
FS1 - 4	86.07.22	12 m	349	352	352	✓
FS1 - 5	86.07.22	12 m	350	353	353	✓
FS1 - 9	86.07.22	12 m	350	352	352	✓
FS1 - 10	86.07.22	12 m	350	353	353	✓
FS1 - 11	86.07.24	12 m	350	353	353	✓
FS1 - 12A	86.07.24	12 m	350	353	353	✓
FS1 - 12B	86.07.24	12 m	350	353	353	✓

ALL RESISTANCES ACCURATE ± 1 COUNT - FLUKE 77 MULTIMETER

ARCTEC CANADA LIMITED

ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452

PROJECT M.V. KALVIK INSTRUMENTATION

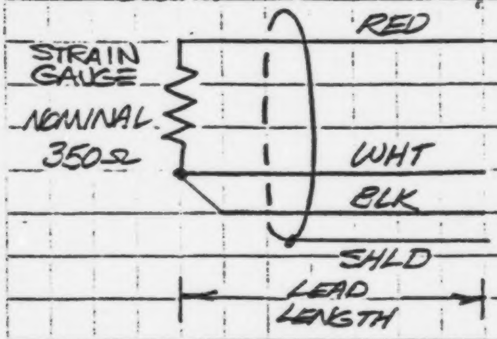
SUBJECT FORWARD-AFT STRAIN GAUGES DATA SUMMARY

SHEET 4 OF 6

DATE JULY 24/86

BY JDG

CH'K. BY



STRAIN GAUGES: MICRO-MEASUREMENTS CEA-06-125 UW -350

LEAD WIRE: THERMAX 36 GAUGE STRANDED TEFLON JACKET & INSULATION 3 CONDUCTOR PLUS SHIELD

SOLDER: KESTER SN63 WITH ANTIMONY (361°)

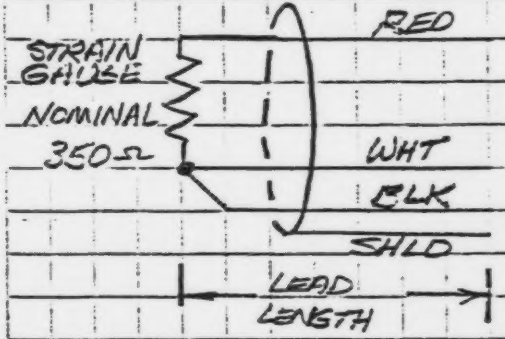
GAUGE NO: (CABLE ID)	DATE	LEAD LENGTH	GAUGE RESISTANCE (NO LEADS)	OVERALL RESISTANCE (WITH LEADS) RED-WHT	RED-BLK	GROUND CHECK (NO SHORT TO SHIELD)
FA1-1A	86.07.24	20m	350Ω	354Ω	354Ω	✓
FA1-1B	86.07.24	20m	350	355	355	✓
FA1-2	86.07.24	20m	350	355	355	✓
FA1-3	86.07.24	20m	350	355	355	✓
FA1-5	86.07.24	20m	350	355	355	✓
FA1-7	86.07.24	20m	350	355	355	✓
FA1-9	86.07.24	20m	351	356	356	✓
FA1-11	86.07.24	20m	351	356	356	✓
FA1-12A	86.07.24	20m	350	355	355	✓
FA1-12B	86.07.24	19m	350	355	355	✓

ALL RESISTANCES ACCURATE ± 1 COUNT - FLUKE 77 MULTIMETER

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT M.V. KALVIK INSTRUMENTATION
SUBJECT AFT - AFT STRAIN GAUGES

SHEET 5 OF 6
DATE JULY 24/86
BY JDG
CH'K. BY



STRAIN GAUGES: MICRO - MEASUREMENTS
CEA - 06 - 125 UW - 350

LEAD WIRE: THERMAX 26 GAUGE SHIELDED
TEFLON JACKET & INSULATION
3 CONDUCTOR PLUS SHIELD

SOLDER: KESTER SN63 WITH ANTIMONY (361°)

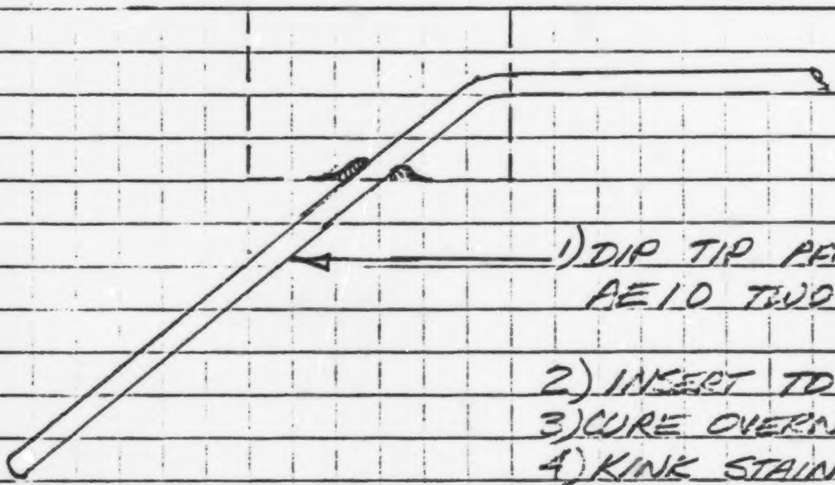
GAUGE NO. (CABLE ID)	DATE	LEAD LENGTH	GAUGE RESISTANCE (NO LEADS)	OVERALL RESISTANCE (WITH LEADS)		GROUND CHECK (NO SHORT TO SHLD)
				RED - WHT	RED - BLK	
AA1A - 1A	86.07.24	20m	350 Ω	355 Ω	355 Ω	✓
AA1A - 1B	86.07.24	20m	350	355	355	✓
AA1A - 2A	86.07.24	20m	350	355	355	✓
AA1A - 2B	86.07.24	20m	350	355	355	✓
AA1A - 3	86.07.24	20m	350	355	355	✓
AA1A - 4	86.07.24	20m	350	355	355	✓
AA1A - 5	86.07.24	20m	350	355	355	✓
AA1A - 9	86.07.24	20m	350	355	355	✓
AA1A - 10	86.07.24	20m	351	356	356	✓
AA1A - 11	86.07.24	20m	351	356	356	✓
AA1A - 12A	86.07.24	20m	350	355	355	✓
AA1A - 12B	86.07.24	20m	350	355	355	✓
AA1A - 12C	86.07.24	20m	350	355	355	✓

ALL RESISTANCES ACCURATE ± 1 COUNT - FLUKE 77 MULTIMETER

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT M.V. KALVIK INSTRUMENTATION
SUBJECT THERMOCOUPLE INSTALLATION
SHEET 6 OF 6
DATE JULY 24/86
BY JDG
CH'K. BY

GLUEING :



1) DIP TIP APPROX 3/4" IN AE10 TWO PART EPOXY.

2) INSERT TO FULL DEPTH
3) CURE OVERNIGHT ≥ 12HRS
4) KINK STAINLESS TUBE TO HOLD INTO CORNER OF GROOVE.
5) POT IN M-COAT J POLYSULPHIDE ALONG WITH STRAIN GAUGE.

ALL THERMOCOUPLES INSTALLED JULY 24/86
APPROX 3:00 PM

M-LINE ACCESSORIES
Instruction Bulletin B-137-11

Strain Gage Applications with M-Bond AE-10/15 and M-Bond GA-2 Adhesive Systems

I. GENERAL DESCRIPTION

The three adhesives described in this bulletin, AE-10, AE-15, and GA-2 are all 100% solids epoxy systems for use with Strain Gages, Temperature Sensor Gages, and –S/N–® Fatigue Life Gages. The gage installation procedure described is appropriate for each adhesive, the primary differences in the systems being in mixing instructions, pot life, cure cycles, and to some extent, elongation properties. Each system is effective from the cryogenic region to +200°F *(+95°C)*. M-BOND AE-10 is packaged together with the AE-15 System, while M-BOND GA-2 is packaged separately.

HANDLING PRECAUTIONS

While these bonding agents are considered relatively safe to handle, contact with skin and inhalation of their vapors should be avoided. Immediate washing with ordinary soap and water is effective in cleansing skin contact. For eye contact rinse thoroughly with a copious amount of water and consult a physician.

II. MIXING INSTRUCTIONS AND ADHESIVE CHARACTERISTICS

A. General

1. Each kit contains materials for mixing six batches of adhesive.
2. Any resin removed from refrigeration must be allowed to attain room temperature equilibrium before being opened.
3. Mix adhesives thoroughly for five minutes according to instructions. If a room-temperature cure is used, allow the freshly mixed adhesive to stand an additional five minutes before use.
4. The pot life for Systems AE-10 and GA-2 can be prolonged by occasionally stirring to prevent localized exotherm in the center of the resin system or by pouring it out onto a chemically clean metal plate.

Note: During storage, crystals may form in the Resin AE. These crystals do not affect adhesive performance, but should be reliquefied prior to mixing by warming the resin bottle to +120°F (+50°C) for approximately one-half hour. Allow the resin to return to room temperature equilibrium before adding curing agent; excess heat will shorten mixed pot life.

B. M-Bond AE-10/15 Adhesive Kit

AE-10 System: Resin AE (10.0-gram units) with Curing Agent 10 will cure at 70°F *(21°C)* in 6 hours, with approximately 6% elongation capabilities and essentially creep-free performance. Elongation capabilities of approximately 10% can be obtained by extending the cure time to 24 to 48 hours at 75°F *(24°C)*.* To mix, fill one of the calibrated droppers with Curing Agent 10 exactly to the number 10 and dispense the contents into the center of the jar of Resin AE. *Immediately cap the bottle of Curing Agent 10 to avoid moisture absorption.* Mix the Resin AE and Curing Agent 10 thoroughly for 5 minutes, using one of the plastic stirring rods. The pot life or working time after mixing is 10 to 20 minutes. Discard the dropper and stirring rod after use.

AE-15 System: Resin AE (10.0-gram units) with Curing Agent 15 requires moderately elevated curing temperatures, and is recommended for critical installations, such as strain gage transducers, where zero shift and hysteresis must be minimized. The AE-15 system is also useful with high elongation strain gages at strain levels up to approximately 10% to 15% at 70°F *(21°C)*, and at strain levels up to 15% at 200°F *(95°C)*. To mix, fill one of the calibrated droppers with Curing Agent 15 exactly to the number 15 and dispense the contents into the center of the jar of Resin AE. *Immediately cap the bottle of Curing Agent 15 to avoid moisture absorption.* Mix the Resin AE and the Curing Agent 15 thoroughly for 5 minutes, using one of the plastic stirring rods. The pot life, or working time after mixing is approximately 1½ hours at 70°F *(21°C)*. Discard the dropper and stirring rod after use.

Resin GA-2 (15.0-gram units) is a partially filled 100% solids epoxy adhesive. Resin GA-2 with Hardener 10-A will have approximately 10% to 15% elongation capabilities when cured for 40 hours at 70°F *(21°C)*. The GA-2 adhesive system will have approximately 6% elongation capabilities when cured for 6 hours at 70°F *(21°C)*. To mix, fill one of the calibrated droppers with Hardener 10-A exactly to the number 10, and dispense the contents into the jar of Resin GA-2. *Immediately cap the bottle of Hardener 10-A to prevent moisture absorption.* Mix the Resin GA-2 and the Hardener 10-A thoroughly for 5 minutes using one of the plastic stirring rods. Pot life or working time is approximately 15 minutes at 70°F *(21°C)*. Discard the dropper and stirring rod after use.

Refer to Instruction Bulletin B-129, and Tech Tip TT-605 for discussions of high-elongation strain measurements.

Micro-Measurements Division
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III. GAGE INSTALLATION PROCEDURE

Step 1

The surface preparation technique used is the same basic cleaning procedure described in M-M Instruction Bulletin B-129, *"Surface Preparation for Strain Gage Bonding"*. The initial step is to thoroughly degrease with solvents such as Chlorothene SM or Freon TF (Fig. 1). Chlorothene SM is preferred whenever possible since a chlorinated degreaser is very active. Some materials will react with chlorinated degreasers, for which Freon is an excellent substitute. Any degreasing should be done with clean solvents. Thus the use of a "one-way" container, such as the aerosol can, is highly advisable.

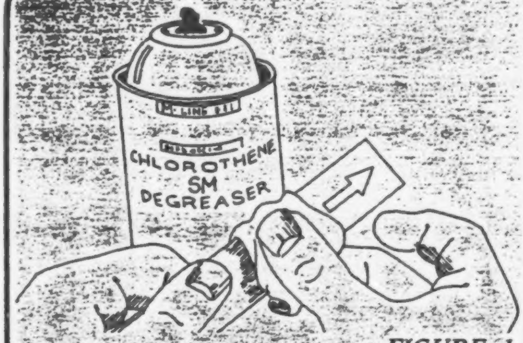


FIGURE 1

Step 2

Dry lap the gaging area with 220- or 320-grit silicon-carbide paper to remove any scale or oxides on the base material (Fig. 2a). Apply M-PREP CONDITIONER A and wet-lap the gage area. Keep the surface wet while lapping. Remove the residue and Conditioner by slowly wiping through the gaging area with a gauze sponge (Fig. 2b). The wet-lap and wiping procedure should then be repeated with 400-grit silicon-carbide paper. With a 4H (hard) drafting pencil on aluminum or a ballpoint pen on steel, burnish whatever alignment marks are needed on the specimen. Rewet the surface with Conditioner A and scrub with cotton tipped applicators until a clean applicator is no longer discolored by the scrubbing. Remove the residue and Conditioner, slowly wiping through the gaging area with a gauze sponge.

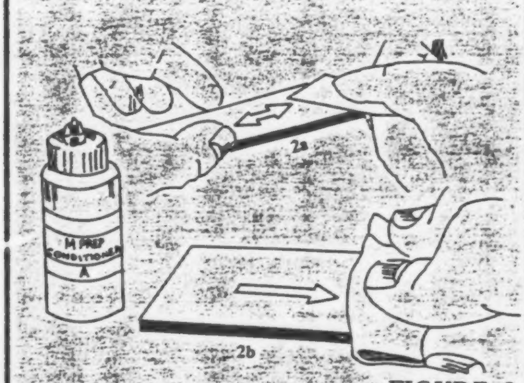


FIGURE 2

Step 3

Apply a liberal amount of M-PREP NEUTRALIZER 5 to the gage area. Keeping the surface wet, scrub with cotton tipped applicators (Fig. 3). Do not allow evaporation of the cleaning material on the specimen surface since this would leave a thin, unwanted film between the adhesive and the specimen. Remove the Neutralizer by slowly wiping through the gage area, allowing the gauze sponge to absorb the Neutralizer. ***Do not wipe back and forth over the gage area since this may allow contaminants to be redeposited on the cleaned area.***

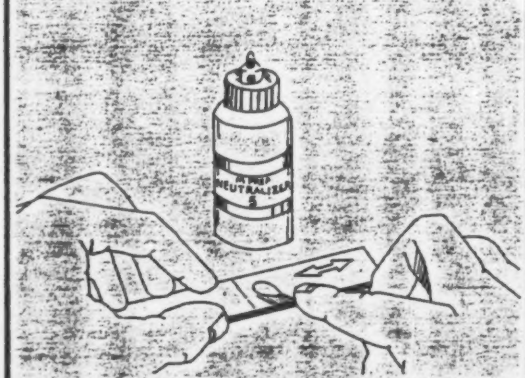


FIGURE 3

Step 4

Remove the gage from the acetate envelope by grasping the edge of the gage backing with tweezers, and place on a chemically clean glass plate or empty gage box with the bonding side of the gage down. If a solder terminal is to be incorporated, position it on the plate adjacent to the gage as shown. A space of approximately 1/16 in *(1.6 mm)* should be left between the gage backing and terminal. Use 4 to 6 in *(100 to 150 mm)* of M-M Part No. PCT-2 cellophane tape as a carrier to aid in positioning the strain gage and terminal. (When cure temperatures exceed +175°F *(+80°C)*, M-M Part No. MJG-2 Mylar tape must be substituted for the cellophane tape.) Tack one end of the tape to the glass plate behind the gage and terminal, and wipe forward onto the terminal and gage. Carefully lift the tape at a shallow angle (about 45 degrees to specimen surface), bringing the gage up with it (Fig. 4).

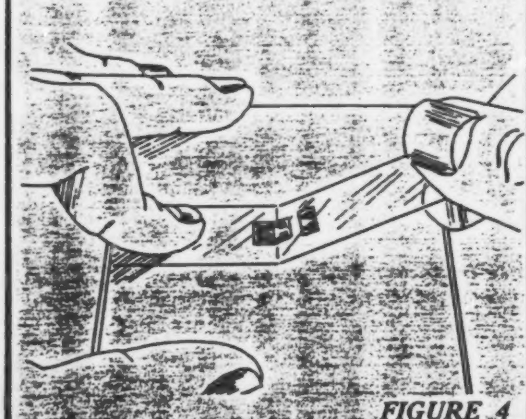


FIGURE 4

Step 5

Position the gage/tape assembly so the triangle alignment marks on the gage are over the layout lines on the specimen (Fig. 5). Holding the tape at a shallow angle, wipe the assembly onto the specimen surface. If the assembly appears to be misaligned, lift one end of the tape at a shallow angle until the assembly is free of the specimen. Realign properly and firmly anchor down at least one end of the tape to the specimen. This realignment can be done without fear of contamination by the tape mastic if the recommended cellophane tape is used. This tape will retain the mastic when removed.

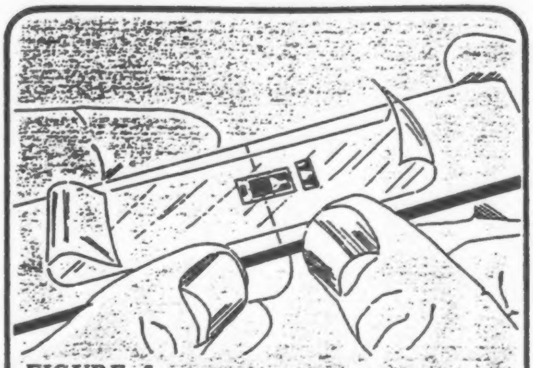


FIGURE 5

Step 6

Lift one end of the tape at a shallow angle to surface (about 45 degrees) until gage and terminal are free of specimen surface (Fig. 6a). Tuck loose end of tape under and press to surface so the gage lies flat with the bonding side exposed (Fig. 6b). In some cases this may be difficult because of space limitations. If this situation occurs, leave enough slack in the tape to allow a finger to be slipped behind the gage to support it while applying the adhesive (Step 7).

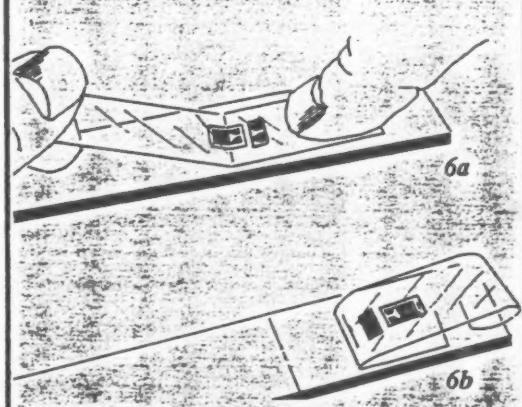


FIGURE 6

Step 7

Coat specimen and back of gage with the prepared adhesive. The mixing rod can be used to apply a thin layer of adhesive over both surfaces (Fig. 7). ***Be careful not to pick up any unmixed components of the adhesive.*** To insure this, it is advisable to wipe the mixing rod clean and then pick up a very small amount of the adhesive from the center area of the adhesive jar. Immediately after coating the gage and specimen with adhesive, proceed without delay to Step 8. This will limit the absorption of moisture by the uncured adhesive, and the cellophane tape will serve as a temporary moisture barrier during curing.

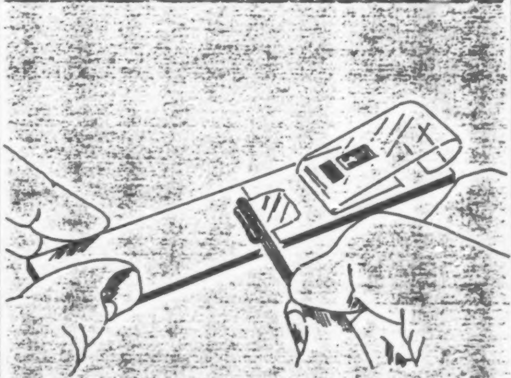


FIGURE 7

Step 8

Lift tucked-over end of tape and bridge over adhesive at approximately a 30-degree angle. With a piece of gauze, slowly make a single wiping stroke over the gage/tape assembly, bringing the gage back down over the alignment marks on the specimen. Use a firm pressure with your fingers when wiping over the gage, since the adhesive is quite viscous (Fig. 8). A very thin layer of adhesive is desired for optimum bond performance.

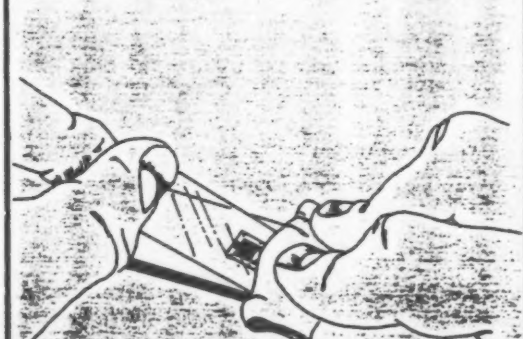


FIGURE 8

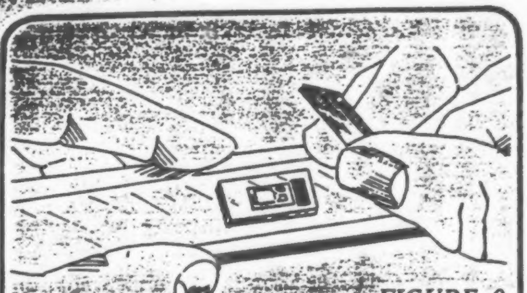


FIGURE 9

Step 9

Place silicone gum pad and backup plate over the gage installation (Fig. 9). The silicone gum should be soft (Durometer A40-60) and at least 3/32 in *(2.5 mm)* thick. This will allow the clamping force to be exerted evenly over the gage. The area of the silicone gum pad should be used to compute the final clamping pressure.

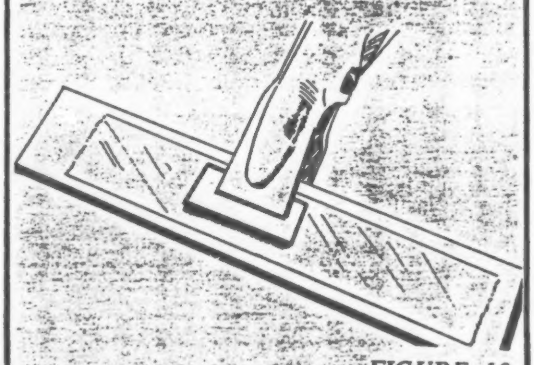


FIGURE 10

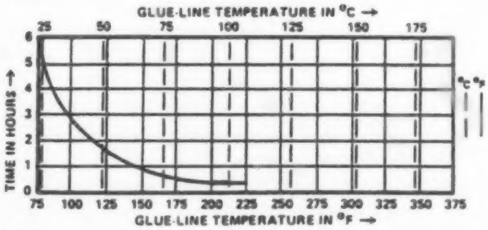
Step 10

Apply force by spring clamp or dead weight until a clamping pressure of 5 to 20 psi *(35 to 135 kN/m²)* is attained (Fig. 10). Take special care in making sure the clamping pressure is equal over the entire gage. Unequal clamping pressure may result in an irregular glue line. Take steps to insure that the clamps will not slide out of position during cure. A few strips of tape to assist in holding the clamps or backup plate in place during cure may be helpful.

IV. RECOMMENDED CURE SCHEDULES

M-BOND AE-10 and GA-2

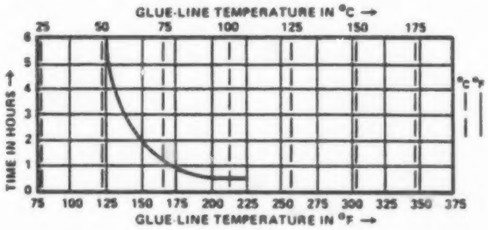
Caution: These systems will not cure properly below 70°F *(21°C)*.



Postcuring the installation for two hours at least +25°F *(+15°C)* above the maximum operating temperature with the clamping fixture removed will provide essentially creep-free performance.

M-BOND AE-15

Caution: To ensure proper polymerization, the cure cycle should start within 1.5 hours after mixing.



Note:

Do not exceed +225°F (+105°C) cure temperature.

V. FINAL INSTALLATION PROCEDURE

1. Select appropriate solder and attach leadwires. Remove solder flux with Rosin Solvent. See *M-M Catalog A-110* for these materials.
2. Select and apply protective coating. See *M-M Catalog A-110.*
3. Micro-Measurements gages have been treated for optimum bonding conditions and require no precleaning before use unless contaminated during handling. If contaminated, the back of any gage may be cleaned with a cotton applicator slightly moistened with Neutralizer 5.

APPENDIX A (ii

M-LINE ACCESSORIES
Instruction Bulletin B-147

Application of M-Coat J and JL Protective Coatings

GENERAL INFORMATION

M-Coat J and JL are two-part polysulfide liquid polymer compounds for environmental protection of strain gage installations. When fully cured, these compounds form a rubber-like covering that provides an effective barrier against water and many other fluids. The tough coating also protects installations from mechanical damage.

M-Coat J has a paste-like consistency when mixed, and can be spread to the desired thickness with a spatula. Because it will not run or sag, it can be applied to vertical or overhanging surfaces.

M-Coat JL has the consistency of thick paint when mixed. It can be poured or brushed on gage installations, and is frequently used as a potting compound.

Operating temperature range for both materials is from -50° to +200°F *(-45° to +95° C)* for long-term service, and to +250°F *(+120° C)* for short-term service (less than 100 hours). They may be cured at room temperature or at a moderately elevated temperature. The elevated temperature cure will improve moisture resistance, and is recommended for long-term applications.

SHELF LIFE

9 months at +75°F *(+24° C)*.

POT LIFE

30 minutes at +75°F *(+24° C)*.

HANDLING PRECAUTIONS

These polysulfide compounds are safe materials to use when reasonable care is observed. The user is cautioned to: (1) Avoid direct contact with resin or curing agent; (2) Avoid prolonged or repeated breathing of vapors; (3) *Use only in well-ventilated areas.* The use of polyethylene gloves and aprons are recommended. If skin contact does occur, thoroughly flush the contaminated area with warm water. Obtain medical attention in cases of extreme exposure or ingestion. For additional health and safety information, consult the material safety data sheet which is available upon request.

CLEAN-UP AND REMOVAL

Uncured M-Coat J or JL can be removed from tools and working surfaces with a solvent such as Micro-Measurements CSM-1 Degreaser. Fully cured M-Coat J or JL can be removed with commercially available strippers or by mechanical methods.

SURFACE PREPARATION

When preparing a surface for strain gage bonding, always clean an area large enough to include the area to be covered by the protective coating. This will ensure proper adhesion at the outer edges of the coating.

A properly applied protective coating not only seals the gage installation *from* moisture and contaminants, but can also seal them *in*. Therefore, for maximum stability in moist environments, it is important to dry the gage installation with a heat gun before applying coatings. It is also important to remove oils, soldering fluxes, fingerprints and other contaminants from the prepared area. A thorough washing with a clean solvent such as CSM-1 is normally sufficient. The use of the heat gun as a final drying step will help ensure complete evaporation of solvents, as well as moisture, prior to coating application.

GAGE PREPARATION

Exposed electrical connections and the exposed foil of open-faced gages are first covered with a layer of Teflon® tape (supplied in the M-Coat J and JL kits) prior to application of M-Coat J or JL. The Teflon tape provides insulation against electrical leakage, and minimizes gage resistance shifts during the cure cycle.

LEADWIRE PREPARATION

A common cause of failure in strain gage installations is penetration by water or other fluids at the leadwire entrance to the coating. To prevent fluid migration along leadwires and into the gage installation, protective coatings must encapsulate the leadwires to a minimum distance of 1 in *(25 mm)* from the installation.

Prior to treating the leadwires for bonding to the protective coating, the individual conductors of jacketed or ribbon cable should be separated for a distance of several inches from the end.

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(919) 365-3800

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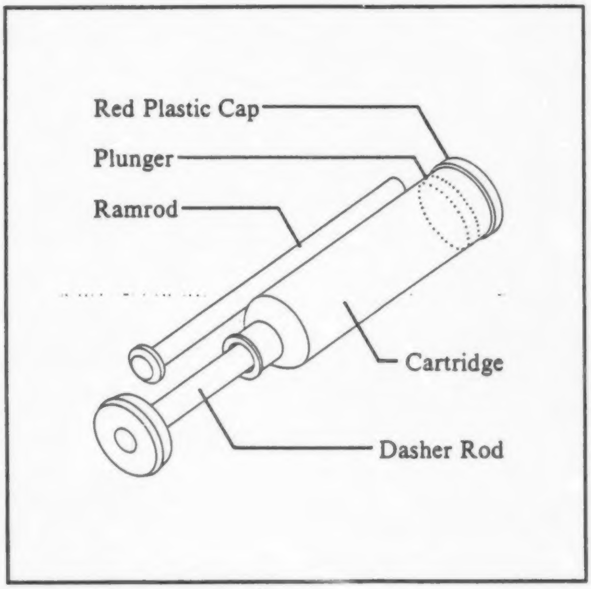
Vinyl-insulated leadwires contain plasticizers that inhibit good coating adhesion. They must be primed with Micro-Measurements M-Coat BT (or M-Coat B), which "bites" into the vinyl insulation and provides a good bonding surface for the subsequent coating of M-Coat J or JL. This primer coating must be air dried for two hours or more prior to application of M-Coat J or JL.

Teflon-insulated leadwires must also be prepared for bonding before a protective coating can be applied. Tetra-Etch compound (Micro-Measurements TEC-1) should be used to treat the Teflon for bonding. M-Coat J and JL will readily bond to treated Teflon without the use of an intermediate primer coating.

MIXING M-COAT J AND JL

M-Coat J and JL are packaged in pre-measured disposable plastic cartridges that allow the material to be stored and mixed in the same container.



1. While holding the cartridge, grasp the dasher rod and extend it fully.
2. Push the ramrod into the hollow end of the dasher rod to inject all of the curing agent (located inside the dasher rod) into the resin.
3. Thoroughly mix the resin and curing agent by moving the dasher rod back and forth, while rotating the dasher in a *clockwise* direction approximately one turn per stroke. Approximately 50 strokes are required to thoroughly mix the material. This procedure normally requires no more than five minutes of mixing time.
4. Pull the dasher rod outward all the way to the neck of the cartridge, and grasp the cartridge firmly. Unscrew the dasher rod by turning *counterclockwise* approximately three turns. Clean the end of the dasher rod with a gauze sponge saturated with CSM-1 Degreaser or similar solvent.
5. Remove the red plastic cap from the cartridge. Dispense the mixed coating onto a clean aluminum or glass plate by pushing the dasher rod into the plunger.

APPLYING M-COAT J AND JL

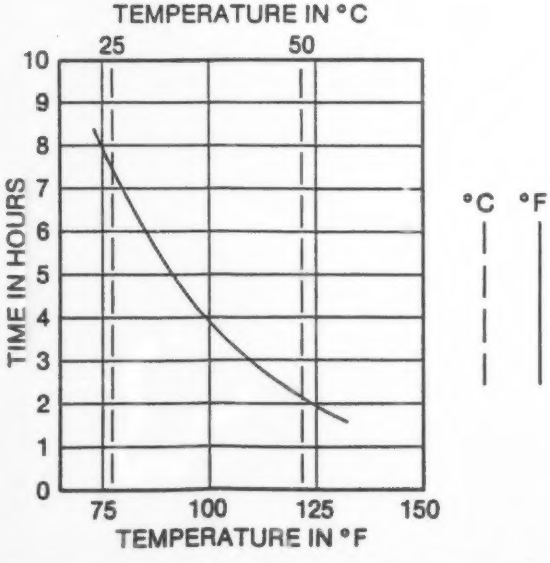
1. Apply a layer of Teflon film over the strain gage grid and exposed solder connections. Allow the film to extend at least 1/4 in *(6 mm)* past the exposed surfaces. Press the film into place.
2. Gently lift the leadwires and, with a spatula (a brush may be used with M-Coat JL), apply a generous amount of coating under the leadwires and over the gage installation.

   Extend the layer at least 1 in *(25 mm)* beyond the edges of the gage backing or bondable terminals, preventing any flow into uncleaned areas of the part surface with masking tape.
3. Press leadwires into the coating, and apply more J or JL over the leadwires and the entire gage installation.
4. Position the leadwires above the specimen surface so they are completely encapsulated and suspended in the coating.

CURING M-COAT J AND JL

Both coatings will become usable in approximately eight hours at room temperature, although M-Coat J will continue to harden and improve its chemical resistance over several days. Moderately elevated temperatures will reduce cure times according to the schedule shown below. Maximum recommended cure temperature is +130°F *(+55°C)*.

Note: Potted connectors or coatings of M-Coat J or JL that exceed 3/8 in *(10 mm)* in thickness should be air dried for 30 minutes at room temperature prior to starting an elevated-temperature cure.



APPENDIX M2(III)
PAGE 1 OF 8

INSTALLED 2 TEST SPECIMENS
STAVES 1-4, ~~8~~, 9, 10 JULY 21/86

MM

ENGINEERING DATA SHEET

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Final QA	Check	Item
F.A.M.	L.P.	R264-08

MM Micro-Measurements Division
MEASUREMENTS GROUP, INC.
RALEIGH, NORTH CAROLINA

PRECISION STRAIN GAGES

CEA-06-125UW-350

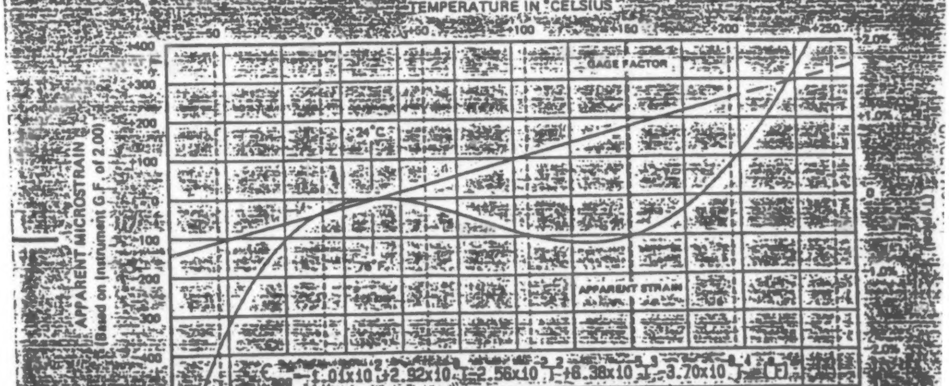
GAGE TYPE	RESISTANCE IN OHMS	GAGE FACTOR AT 75°F	K_t	LOT NUMBER	QUANTITY	OPTION	CODE
CEA-06-125UW-350	350.0 ± 0.3%	2.08 ± 0.5%	+0.3%	R-A38AD457	5 GAGES		952517

GENERAL INFORMATION: SERIES CEA FEATURE GAGES

GENERAL DESCRIPTION:	CEA gages are a general-purpose family of constantan strain gages widely used in experimental stress analysis. The gages are supplied with a fully encapsulated grid and exposed copper-coated integral solder tabs.
TEMPERATURE RANGE:	−100°F *(−75°C)* to +400°F *(+205°C)* for continuous use in static measurements.
SELF-TEMPERATURE COMPENSATION:	See data curve below.
STRAIN LIMITS:	Approximately 5% for gage lengths 1/8 in *(3.2 mm)* and larger, and approximately 3% for gage lengths under 1/8 in *(3.2 mm)*.
FATIGUE LIFE:	Fatigue life is a marked function of solder joint formation. With 30-AWG leads directly attached to gage tabs, fatigue life will be 10^5 cycles at ±1500μin/in *(μm/m)* using M-Line 361A Solder.
CEMENTS:	Compatible with M-M Certified M-Bond 200, but it will normally not provide the greatest strain limit. Micro-Measurements' M-Bond AE-10/15, M-Bond GA-2, M-Bond 600, and M-Bond 610 are excellent. M-Bond 610 is the best choice over the entire operating range. Refer to M-M Catalog A-110 for information on bonding agents, and Bulletin B-127, B-130, and B-137 for installation procedures.
SOLDER:	If operating temperature will not exceed +300°F *(+150°C)*, M-Line solder type 361A (63-37) tin-lead solder may be used for lead attachment. M-Line solder type 450 (95-5) tin-antimony is satisfactory to +400°F *(+205°C)*. Refer to M-M Catalog A-110 for further information on solders, and Bulletin TT-608 for lead attachment techniques.
BACKING:	The backing of CEA Series Gages has been specially treated for optimum bond formation with all appropriate strain gage adhesives. No further cleaning is necessary if contamination of the prepared surface is avoided during handling.

FORM: 83-5
CODE: 9640

TEMPERATURE-INDUCED APPARENT STRAIN LOT NO. A38AD457



TESTED ON: 1018 STEEL CODE: 941818 ENG. GEW

TEST PROCEDURES USED BY MICRO-MEASUREMENTS FOR STRAIN GAGE PERFORMANCE EVALUATION

OPTICAL DEFECT ANALYSIS

A(11)
PAGE 2 of 2

FWD AFT JULY 22 2PM 1 + 1 SCRAP
JULY 22 JULY 22 5PM 3

ENGINEERING DATA SHEET

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Final QA	Check	Item
A.M.	L.P.	R264-01

Micro-Measurements
Division
MEASUREMENTS GROUP, INC.
RALEIGH, NORTH CAROLINA

PRECISION STRAIN GAGES

CEA-06-125UW-350

GAGE TYPE	CEA-06-125UW-350
RESISTANCE IN OHMS	350.0 ± 0.3%
GAGE FACTOR AT 75°F	2.08 ± 0.5%
K_t	+0.3%
LOT NUMBER	R-A38AD457
QUANTITY	5 GAGES
OPTION	
CODE	952517

GENERAL INFORMATION: SERIES CEA FEATURE GAGES

GENERAL DESCRIPTION: CEA gages are a general-purpose family of constantan strain gages widely used in experimental stress analysis. The gages are supplied with a fully encapsulated grid and exposed copper-coated integral solder tabs.

TEMPERATURE RANGE: −100°F *(−75°C)* to +400°F *(+205°C)* for continuous use in static measurements.

SELF-TEMPERATURE COMPENSATION: See data curve below.

STRAIN LIMITS: Approximately 5% for gage lengths 1/8 in *(3.2 mm)* and larger; and approximately 3% for gage lengths under 1/8 in *(3.2 mm)*.

FATIGUE LIFE: Fatigue life is a marked function of solder joint formation. With 30-AWG leads directly attached to gage tabs, fatigue life will be 10^5 cycles at ±1500μin/in *(μm/m)* using M-Line 361A Solder.

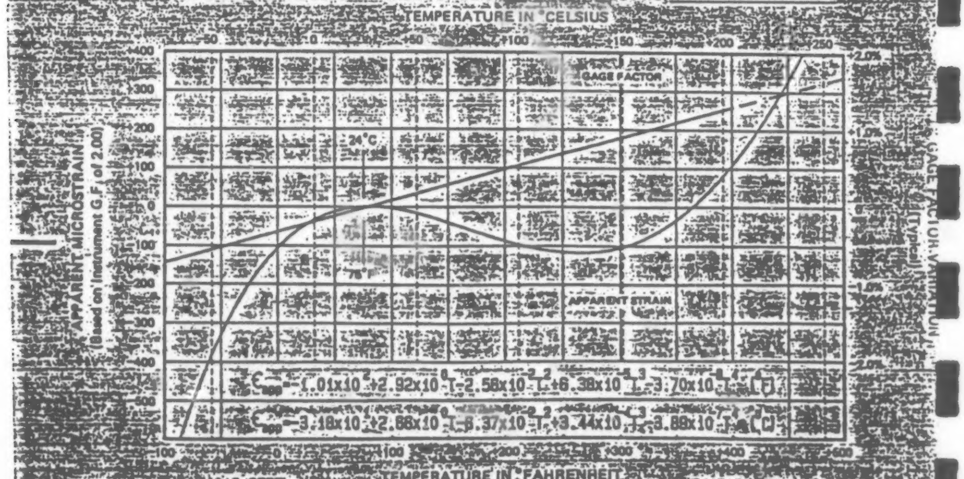
CEMENTS: Compatible with M-M Certified M-Bond 200, but it will normally not provide the greatest strain limit. Micro-Measurements' M-Bond AE-10/15, M-Bond GA-2, M-Bond 600, and M-Bond 610 are excellent. M-Bond 610 is the best choice over the entire operating range. Refer to M-M Catalog A-110 for information on bonding agents, and Bulletin B-127, B-130, and B-137 for installation procedures.

SOLDER: If operating temperature will not exceed +300°F *(+150°C)*, M-Line solder type 361A (63-37) tin-lead solder may be used for lead attachment. M-Line solder type 450 (95-5) tin-antimony is satisfactory to +400°F *(+205°C)*. Refer to M-M Catalog A-110 for further information on solders, and Bulletin TT-608 for lead attachment techniques.

BACKING: The backing of CEA Series Gages has been specially treated for optimum bond formation with all appropriate strain gage adhesives. No further cleaning is necessary if contamination of the prepared surface is avoided during handling.

FORM: 82-
CODE: 9640

TEMPERATURE-INDUCED APPARENT STRAIN LOT NO. R-A38AD457



TESTED ON: 1018 STEEL CODE: 941618 ENG. CEW

TEST PROCEDURES USED BY MICRO-MEASUREMENTS FOR STRAIN GAGE PERFORMANCE EVALUATION

OPTICAL DEFECT ANALYSIS	M-M Procedures and Standar
GAGE FACTOR AT 75°F	ASTM E251-67 (Constant Stress Cantilever Metho
G.F. VARIATION WITH TEMPERATURE	ASTM E251-67 (Beam Deflection Metho

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STERN
Group 1, STAVE 5 July 21 | FWD 1/FT GROUP 1 JULY 22 2PM ~~JUL 22~~

M-M ENGINEERING DATA SHEET

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F.A.M.	L.P.
Final QA	Check

M-M Micro-Measurements Division

MEASUREMENTS GROUP, INC.
RALEIGH, NORTH CAROLINA

PRECISION STRAIN GAGES

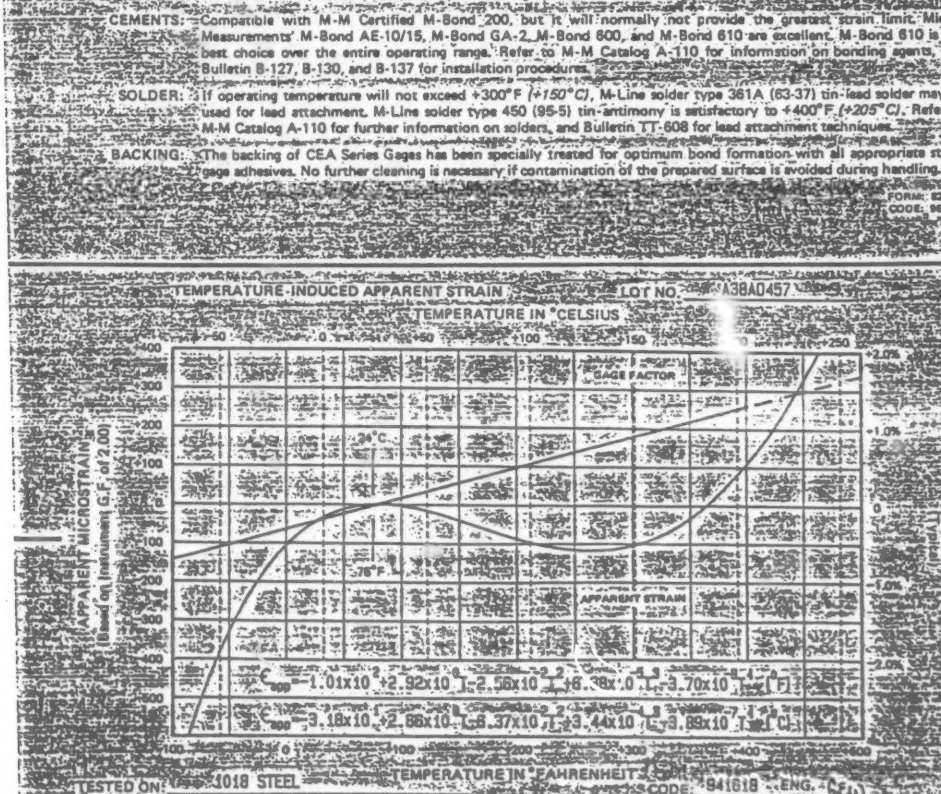
CEA-06-125UW-350	GAGE TYPE
350.0 ± 0.3%	RESISTANCE IN OHMS
2.08 ± 0.5%	GAGE FACTOR AT 75° F
+0.3%	K_t
R-A38AD457	LOT NUMBER
5 GAGES	QUANTITY
	OPTION
952517	CODE

GENERAL INFORMATION: SERIES CEA FEATURE GAGES

GENERAL DESCRIPTION:	CEA gages are a general-purpose family of constantan strain gages widely used in experimental stress analysis. gages are supplied with a fully encapsulated grid and exposed copper-coated integral solder tabs.
TEMPERATURE RANGE:	−100°F *(−75°C)* to +400°F *(+205°C)* for continuous use in static measurements.
SELF-TEMPERATURE COMPENSATION:	See data curve below.
STRAIN LIMITS:	Approximately 5% for gage lengths 1/8 in *(3.2 mm)* and larger; and approximately 3% for gage lengths 1/8 in *(3.2 mm)*.
FATIGUE LIFE:	Fatigue life is a marked function of solder joint formation. With 30-AWG leads directly attached to gage tabs, life will be 10^5 cycles at ±1500μin/in *(μm/m)* using M-Line 361A Solder.
CEMENTS:	Compatible with M-M Certified M-Bond 200, but it will normally not provide the greatest strain limit. Measurements' M-Bond AE-10/15, M-Bond GA-2, M-Bond 600, and M-Bond 610 are excellent. M-Bond 610 is best choice over the entire operating range. Refer to M-M Catalog A-110 for information on bonding agents, Bulletin B-127, B-130, and B-137 for installation procedures.
SOLDER:	If operating temperature will not exceed +300°F *(+150°C)*, M-Line solder type 361A (63-37) tin-lead solder used for lead attachment. M-Line solder type 450 (95-5) tin-antimony is satisfactory to +400°F *(+205°C)*. M-M Catalog A-110 for further information on solders, and Bulletin TT-608 for lead attachment techniques.
BACKING:	The backing of CEA Series Gages has been specially treated for optimum bond formation with all appropriate gage adhesives. No further cleaning is necessary if contamination of the prepared surface is avoided during handling.

FORM:
CODE:

TEMPERATURE-INDUCED APPARENT STRAIN LOT NO. A38AD457



TESTED ON: 1018 STEEL CODE 941618 ENG. CEW

TEST PROCEDURES USED BY MICRO-MEASUREMENTS FOR STRAIN GAGE PERFORMANCE EVALUATION

OPTICAL DEFECT ANALYSIS	M-M Procedures and Stan
GAGE FACTOR AT 75°F	ASTM E251-67 (Constant Stress Cantilever Meth
G.F. VARIATION WITH TEMPERATURE	ASTM E251-67 (Step Deflection M

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JULY 22 2 5 PM
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FWD JUL 22 5
FWD STERN 1-1 1
1-12 2

EMEME

ENGINEERING DATA SHEET

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Final QA	Check
F.A.M.	L.P.

EMEME Micro-Measurements Division

MEASUREMENTS GROUP, INC.
RALEIGH, NORTH CAROLINA

PRECISION STRAIN GAGES

GAGE TYPE	CEA-06-125UW-350
RESISTANCE IN OHMS	350.0 ± 0.3%
GAGE FACTOR AT 75°F	2.08 ± 0.5%
K_t	+0.3%
LOT NUMBER	R-A38AD457
QUANTITY	5 GAGES
OPTION	
CODE	952517

GENERAL INFORMATION: SERIES CEA FEATURE GAGES

GENERAL DESCRIPTION: CEA gages are a general-purpose family of constantan strain gages widely used in experimental stress analysis. The gages are supplied with a fully encapsulated grid and exposed copper-coated integral solder tabs.

TEMPERATURE RANGE: −100°F *(−75°C)* to +400°F *(+205°C)* for continuous use in static measurements.

SELF-TEMPERATURE COMPENSATION: See data curve below.

STRAIN LIMITS: Approximately 5% for gage lengths 1/8 in *(3.2 mm)* and larger, and approximately 3% for gage lengths under 1/8 in *(3.2 mm)*.

FATIGUE LIFE: Fatigue life is a marked function of solder joint formation. With 30-AWG leads directly attached to gage tabs, fatigue life will be 10^5 cycles at ±1500μin/in *(μm/m)* using M-Line 361A Solder.

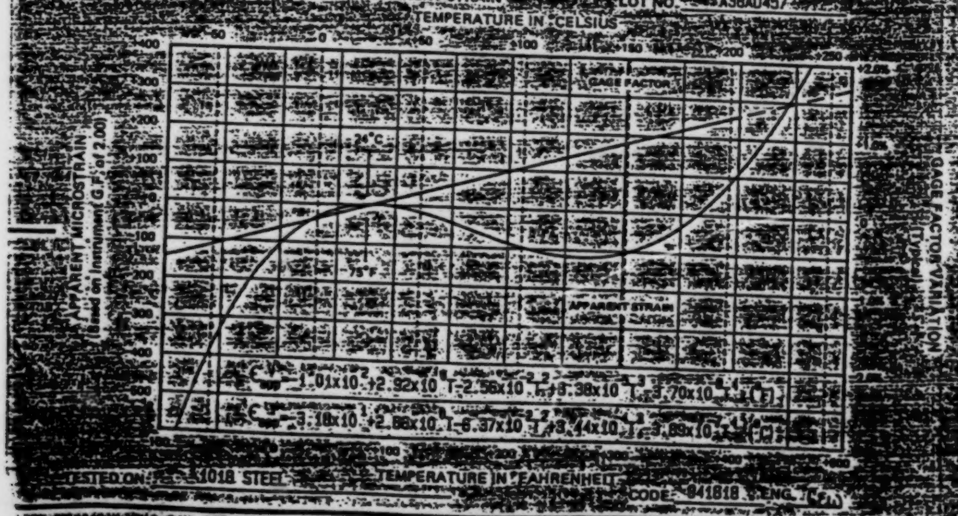
CEMENTS: Compatible with M-M Certified M-Bond 200, but it will normally not provide the greatest strain limit. Micro-Measurements' M-Bond AE-10/15, M-Bond GA-2, M-Bond 600, and M-Bond 610 are excellent. M-Bond 610 is the best choice over the entire operating range. Refer to M-M Catalog A-110 for information on bonding agents, and Bulletin B-127, B-130, and B-137 for installation procedures.

SOLDER: If operating temperature will not exceed +300°F *(+150°C)*, M-Line solder type 361A (63-37) tin-lead solder may be used for lead attachment. M-Line solder type 450 (95-5) tin-antimony is satisfactory to +400°F *(+205°C)*. Refer to M-M Catalog A-110 for further information on solders, and Bulletin TT-608 for lead attachment techniques.

BACKING: The backing of CEA Series Gages has been specially treated for optimum bond formation with all appropriate strain gage adhesives. No further cleaning is necessary if contamination of the prepared surface is avoided during handling.

FORM: 82-404
CODE: 954012

TEMPERATURE-INDUCED APPARENT STRAIN LOT NO. A38AD457



TESTED ON 1018 STEEL

CODE 841818 ENG. Cru

TEST PROCEDURES USED BY MICRO-MEASUREMENTS FOR STRAIN GAGE PERFORMANCE EVALUATION

OPTICAL DEFECT ANALYSIS
GAGE FACTOR AT 75°F — M-M Procedures and Standards
G.F. VARIATION WITH TEMPERATURE — ASTM E251-67 (Constant Stress Cantilever Method)
APPARENT STRAIN VERSUS TEMPERATURE — ASTM E251-67 (Step Deflection Method)
TRANSVERSE SENSITIVITY — ASTM E251-67

M CIII.
Page 5.

JULY 23 FWD STERN 1-2 & 1-11
FWD STERN 1-3, AFT-AFT -1A4, 1A5

M-M ENGINEERING DATA SHEET

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F.A.M.	L.P.
Final QA	Check

M-M Micro-Measurements Division
MEASUREMENTS GROUP, INC.
RALEIGH, NORTH CAROLINA

PRECISION STRAIN GAGES

GAGE TYPE	CEA-06-125UN-350
RESISTANCE IN OHMS	350.0 ± 0.3%
GAGE FACTOR AT 75° F	2.08 ± 0.5%
K	±0.3%
LOT NUMBER	R-A38AD457
QUANTITY	5 GAGES
OPTION	
CODE	952517

GENERAL INFORMATION: SERIES CEA FEATURE GAGES

GENERAL DESCRIPTION: CEA gages are a general-purpose family of constantan strain gages widely used in experimental stress analysis. The gages are supplied with a fully encapsulated grid and exposed copper-coated integral solder tabs.

TEMPERATURE RANGE: −100°F *(−75°C)* to +400°F *(+205°C)* for continuous use in static measurements.

SELF-TEMPERATURE COMPENSATION: See data curve below.

STRAIN LIMITS: Approximately 5% for gage lengths 1/8 in *(3.2 mm)* and larger; and approximately 3% for gage lengths under 1/8 in *(3.2 mm)*.

FATIGUE LIFE: Fatigue life is a marked function of solder joint formation. With 30-AWG leads directly attached to gage tabs, fatigue life will be 10^6 cycles at ±1500μin/in *(μm/m)* using M-Line 361A Solder.

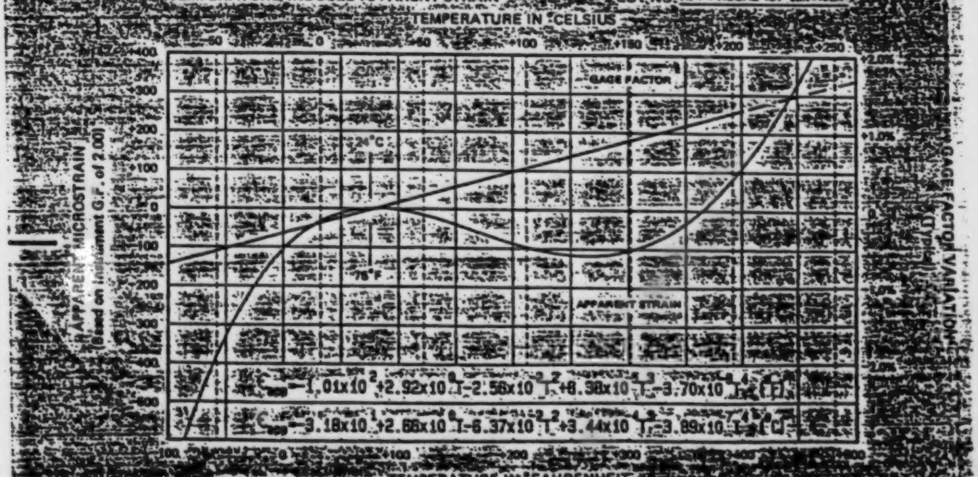
CEMENTS: Compatible with M-M Certified M-Bond 200, but it will normally not provide the greatest strain limit. Micro-Measurements' M-Bond AE-10/15, M-Bond GA-2, M-Bond 600, and M-Bond 610 are excellent. M-Bond 610 is the best choice over the entire operating range. Refer to M-M Catalog A-110 for information on bonding agents, and Bulletin B-127, B-130, and B-137 for installation procedures.

SOLDER: If operating temperature will not exceed +300°F *(+150°C)*, M-Line solder type 361A (63-37) tin-lead solder may be used for lead attachment. M-Line solder type 450 (95-5) tin-antimony is satisfactory to +400°F *(+205°C)*. Refer to M-M Catalog A-110 for further information on solders, and Bulletin TT-608 for lead attachment techniques.

BACKING: The backing of CEA Series Gages has been specially treated for optimum bond formation with all appropriate strain gage adhesives. No further cleaning is necessary if contamination of the prepared surface is avoided during handling.

FORM: [illegible]
CODE: [illegible]

TEMPERATURE-INDUCED APPARENT STRAIN LOT NO. A38AD457



TESTED ON: 1018 STEEL CODE 941818 ENG. [illegible]

TEST PROCEDURES USED BY MICRO-MEASUREMENTS FOR STRAIN GAGE PERFORMANCE EVALUATION

OPTICAL DEFECT ANALYSIS	M-M Procedures and Standards
GAGE FACTOR AT 75°F	ASTM E251-67 (Constant Stress Cantilever Method)
G.F. VARIATION WITH TEMPERATURE	ASTM E251-67 (Step Deflection Method)
APPARENT STRAIN VERSUS TEMPERATURE	ASTM E251-67 (Slow Heating Rate, Continuously Recorded)
TRANSVERSE SENSITIVITY	[illegible] ASTM E251-67
INITIAL RESISTANCE	M-M Procedures, Direct NBS Traceability on Resistance Standards
FATIGUE LIFE	[illegible]

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Page 6 of

JUL 4 23 AFT AFT 1A-12(1), 1A-11, 1A-1(1), 1A-2(2)

M-M

ENGINEERING DATA SHEET

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F.A.M.	L.P.	[illegible]
Final QA	Check	Ir

M-M Micro-Measurements Division
MEASUREMENTS GROUP, INC.
RALEIGH, NORTH CAROLINA

PRECISION STRAIN GAGES

CEA-06-125UW-350

GAGE TYPE: CEA-06-125UW-350
RESISTANCE IN OHMS: 350.0 ± 0.3%
GAGE FACTOR AT 75°F: 2.08 ± 0.5%
K_t: +0.3%
LOT NUMBER: R-A38AD457
QUANTITY: 5 GAGES
OPTION:
CODE: 952517

GENERAL INFORMATION: SERIES CEA FEATURE GAGES

GENERAL DESCRIPTION: CEA gages are a general-purpose family of constantan strain gages widely used in experimental stress analysis. The gages are supplied with a fully encapsulated grid and exposed copper-coated integral solder tabs.

TEMPERATURE RANGE: −100°F *(−75°C)* to +400°F *(+205°C)* for continuous use in static measurements.

SELF-TEMPERATURE COMPENSATION: See data curve below.

STRAIN LIMITS: Approximately 5% for gage lengths 1/8 in *(3.2 mm)* and larger; and approximately 3% for gage lengths under 1/8 in *(3.2 mm)*.

FATIGUE LIFE: Fatigue life is a marked function of solder joint formation. With 30-AWG leads directly attached to gage tabs, fatigue life will be 10^6 cycles at ±1500μin/in *(μm/m)* using M-Line 361A Solder.

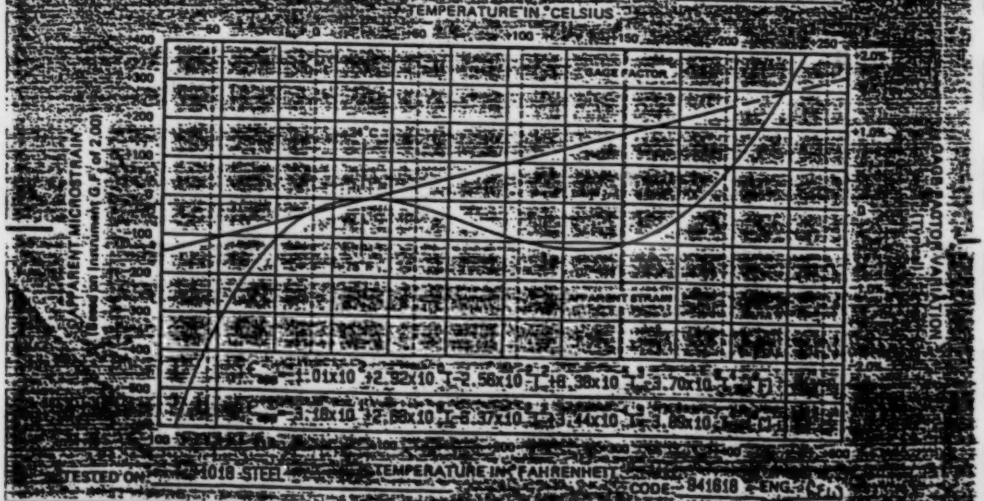
CEMENTS: Compatible with M-M Certified M-Bond 200, but it will normally not provide the greatest strain limit. Micro-Measurements' M-Bond AE-10/15, M-Bond GA-2, M-Bond 600, and M-Bond 610 are excellent. M-Bond 610 is the best choice over the entire operating range. Refer to M-M Catalog A-110 for information on bonding agents, and Bulletin B-127, B-130, and B-137 for installation procedures.

SOLDER: If operating temperature will not exceed +300°F *(+150°C)*, M-Line solder type 361A (63-37) tin-lead solder may be used for lead attachment. M-Line solder type 450 (95-5) tin-antimony is satisfactory to +400°F *(+205°C)*. Refer to M-M Catalog A-110 for further information on solders, and Bulletin TT-608 for lead attachment techniques.

BACKING: The backing of CEA Series Gages has been specially treated for optimum bond formation with all appropriate strain gage adhesives. No further cleaning is necessary if contamination of the prepared surface is avoided during handling.

FORM: 82-304
CODE: 84012

TEMPERATURE-INDUCED APPARENT STRAIN LOT NO. R-A38AD457



TESTED ON 1018 STEEL
CODE 841818 ENG. [illegible]

TEST PROCEDURES USED BY MICRO-MEASUREMENTS FOR STRAIN GAGE PERFORMANCE EVALUATION

OPTICAL DEFECT ANALYSIS
GAGE FACTOR AT 75°F ... ASTM E251-67 (Constant Stress Cantilever Method)
G.F. VARIATION WITH TEMPERATURE ... ASTM E251-67 (Strip Deflection Method)
APPARENT STRAIN VERSUS TEMPERATURE ... ASTM

JULY 23 AFT AFC 1A-9, 1A-10, 1A-3, 1A-12 (2)

M-M

ENGINEERING DATA SHEET

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Final QA	Check	Item
F.A.M.	L.P.	R-244-OP

M-M Micro-Measurements Division

MEASUREMENTS GROUP, INC.
RALEIGH, NORTH CAROLINA

PRECISION STRAIN GAGES

	CEA-06-125UW-350
GAGE TYPE	CEA-06-125UW-350
RESISTANCE IN OHMS	350.0 ± 0.3%
GAGE FACTOR AT 75°F	2.08 ± 0.5%
K_t	+ 0.3%
LOT NUMBER	R-A38AD457
QUANTITY	5 GAGES
OPTION	
CODE	952517

GENERAL INFORMATION: SERIES CEA FEATURE GAGES

GENERAL DESCRIPTION: CEA gages are a general-purpose family of constantan strain gages widely used in experimental stress analysis. The gages are supplied with a fully encapsulated grid and exposed copper-coated integral solder tabs.

TEMPERATURE RANGE: −100°F *(−75°C)* to +400°F *(+205°C)* for continuous use in static measurements.

SELF-TEMPERATURE COMPENSATION: See data curve below.

STRAIN LIMITS: Approximately 5% for gage lengths 1/8 in *(3.2 mm)* and larger; and approximately 3% for gage lengths under 1/8 in *(3.2 mm)*.

FATIGUE LIFE: Fatigue life is a marked function of solder joint formation. With 30-AWG leads directly attached to gage tabs, fatigue life will be 10^5 cycles at ±1500µin/in *(µm/m)* using M-Line 361A Solder.

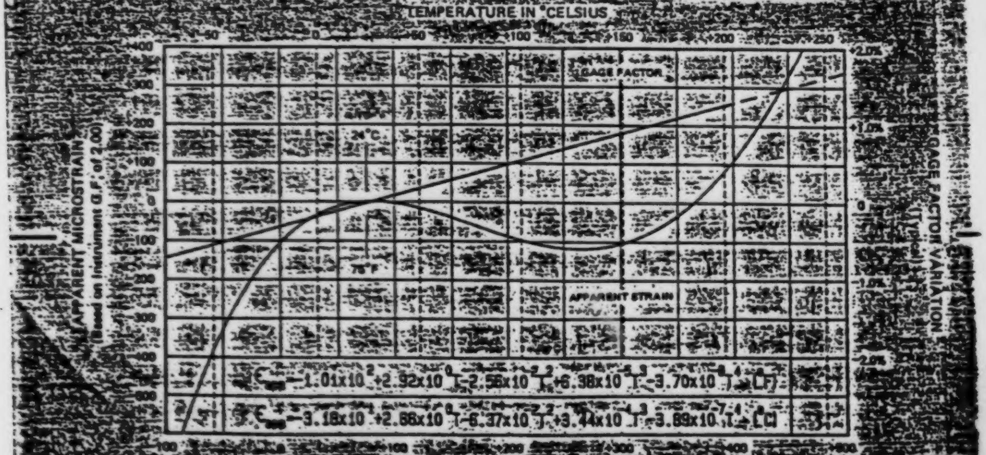
CEMENTS: Compatible with M-M Certified M-Bond 200, but it will normally not provide the greatest strain limit. Micro-Measurements' M-Bond AE-10/15, M-Bond GA-2, M-Bond 600, and M-Bond 610 are excellent. M-Bond 610 is the best choice over the entire operating range. Refer to M-M Catalog A-110 for information on bonding agents, and Bulletin B-127, B-130, and B-137 for installation procedures.

SOLDER: If operating temperature will not exceed +300°F *(+150°C)*, M-Line solder type 361A (63-37) tin-lead solder may be used for lead attachment. M-Line solder type 450 (95-5) tin-antimony is satisfactory to +400°F *(+205°C)*. Refer to M-M Catalog A-110 for further information on solders, and Bulletin TT-608 for lead attachment techniques.

BACKING: The backing of CEA Series Gages has been specially treated for optimum bond formation with all appropriate strain gage adhesives. No further cleaning is necessary if contamination of the prepared surface is avoided during handling.

FORM: [illegible]
CODE: [illegible]

TEMPERATURE-INDUCED APPARENT STRAIN LOT NO. A38A0457



TESTED ON 1018 STEEL CODE 841818 ENG. CFH

TEST PROCEDURES USED BY MICRO-MEASUREMENTS FOR STRAIN GAGE PERFORMANCE EVALUATION

OPTICAL DEFECT ANALYSIS	M-M Procedures and Standards
GAGE FACTOR AT 75°F	ASTM E251-67 (Constant Stress Cantilever Method)
G.F. VARIATION WITH TEMPERATURE	ASTM E251-67 (Step Deflection Method)
APPARENT STRAIN VERSUS TEMPERATURE	ASTM E251-67 (Slow Heating Rate, Continuously Recorded)
TRANSVERSE SENSITIVITY	ASTM E251-67
INITIAL RESISTANCE	M-M Procedure, Direct NBS Traceability on Resistance Standards
FATIGUE LIFE	NAS 942 (Modified)
STRAIN LIMITS	

JUL 72 AF AF [illegible] A-1(C)

M-M

ENGINEERING DATA SHEET

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Final QA	Check	Item
F.A.M.	[illegible]	[illegible]

M-M Micro-Measurements Division

MEASUREMENTS GROUP, INC.
RALEIGH, NORTH CAROLINA

PRECISION STRAIN GAGES

CEA-06-125UN-350

GAGE TYPE: CEA-06-125UN-350

RESISTANCE IN OHMS: 350.0 ± 0.3%

GAGE FACTOR AT 75°F: 2.08 ± 0.5%

K: 0.3%

LOT NUMBER: R-A38AD457

QUANTITY: 5 GAGES

OPTION:

CODE: 952517

GENERAL INFORMATION: SERIES CEA FEATURE GAGES

GENERAL DESCRIPTION: CEA gages are a general-purpose family of constantan strain gages widely used in experimental stress analysis. The gages are supplied with a fully encapsulated grid and exposed copper-coated integral solder tabs.

TEMPERATURE RANGE: −100°F *(−75°C)* to +400°F *(+205°C)* for continuous use in static measurements.

SELF-TEMPERATURE COMPENSATION: See data curve below.

STRAIN LIMITS: Approximately 5% for gage lengths 1/8 in *(3.2 mm)* and larger; and approximately 3% for gage lengths under 1/8 in *(3.2 mm)*.

FATIGUE LIFE: Fatigue life is a marked function of solder joint formation. With 30-AWG leads directly attached to gage tabs, fatigue life will be 10^5 cycles at ±1500μin/in *(μm/m)* using M-Line 361A Solder.

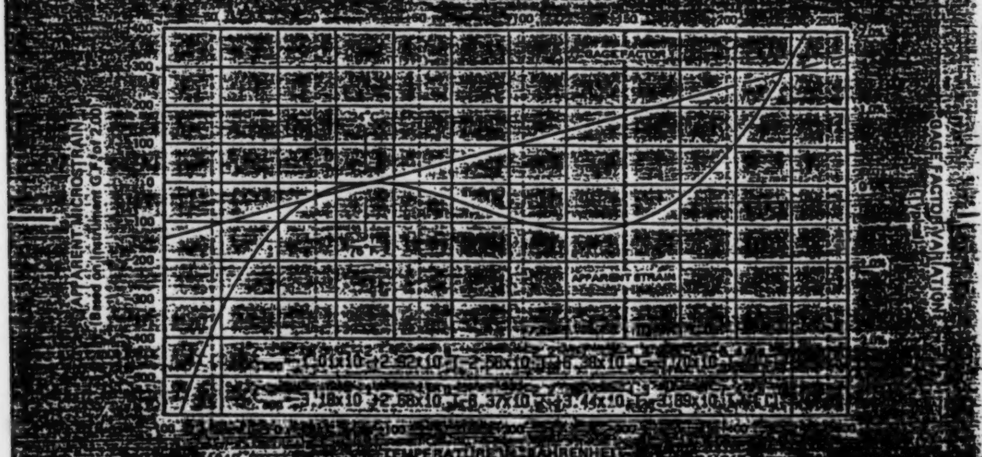
CEMENTS: Compatible with M-M Certified M-Bond 200, but it will normally not provide the greatest strain limit. Micro-Measurements M-Bond AE-10/15, M-Bond GA-2, M-Bond 600, and M-Bond 610 are excellent. M-Bond 610 is the best choice over the entire operating range. Refer to M-M Catalog A-110 for information on bonding agents, and Bulletin B-127, B-130, and B-137 for installation procedures.

SOLDER: If operating temperature will not exceed +300°F *(+150°C)*, M-Line solder type 361A (63-37) tin-lead solder may be used for lead attachment. M-Line solder type 450 (95-5) tin-antimony is satisfactory to +400°F *(+205°C)*. Refer to M-M Catalog A-110 for further information on solders, and Bulletin TT-608 for lead attachment techniques.

BACKING: The backing of CEA Series Gages has been specially treated for optimum bond formation with all appropriate strain gage adhesives. No further cleaning is necessary if contamination of the prepared surface is avoided during handling.

FORM: [illegible]
CODE: [illegible]

TEMPERATURE-INDUCED APPARENT STRAIN LOT NO. R-A38AD457



TESTED ON: 1018 STEEL

CODE: 841818

TEST PROCEDURES USED BY MICRO-MEASUREMENTS FOR STRAIN GAGE PERFORMANCE EVALUATION

OPTICAL DEFECT ANALYSIS	M-M Procedures and [illegible]
GAGE FACTOR AT 75°F	ASTM E251-67 (Constant Stress Cantilever Method)
G.F. VARIATION WITH TEMPERATURE	ASTM E251-67 (Beam Deflection Method)
APPARENT STRAIN VERSUS TEMPERATURE	ASTM E251-67 (Slow Heating Rate, Continuously [illegible])
TRANSVERSE SENSITIVITY	ASTM E251-67
INITIAL RESISTANCE	M-M Procedure, Direct NBS Traceability on Resistance [illegible]
FATIGUE LIFE	NAS 942 [illegible]
STRAIN LIMITS	NAS 942 [illegible]
GAGE THICKNESS	[illegible]

LABORATORY TESTING OF RUBBER BEARING

FOR

PROJECT 2452

PROPULSION SYSTEM FULL SCALE TESTS AND ANALYSIS ON THE M.V. KALVIK

JULY 17-19, 1986

BY

ARCTEC CANADA LIMITED

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3.4 Test 6 Results 4
3.5 Test 7 Results 4
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Appendix A Test Results
Appendix B Working Notes

Section 1 Test Summary

The aim of the Material testing task was the following:

1) establish the properties of the rubber material
2) establish the durability of the strain gauges under the expected high strain
3) compare the actual strain measured externally to the strain measured by the strain gauge
4) check the proposed installation method for durability in a water environment

A series of 8 different tests were conducted in the test program. There was no failure of the gauge in any cases. The rubber exhibits the property of having a dual modulus.

Section 1.1 Test Personnel

Personnel performing the laboratory tests were Ron Ritch and Jim Gillespie

Section 2. Test Preparation

Section 2.1 Test Preparation of Rubber Bearing

A sample 6 inches long section of rubber bearing was machined in the proposed manner as the actual staves. A slot was milled the length of the section and a gauge "pocket" was machined to coincide with the slot.

The strain gauge was glued in place using Micro-measurement AE-10 and cured for 12 hours. The gauge was then wired and the "pocket" and the milled slot and "pocket filled with M-coat J.

Section 2.2 Test Preparation of Loading Platens

Loading Platens were created by casting molds of the rubber bearing with SCOTCHCAST 10. The molds were backed by 1/2 inch steel plates. After 6 hours the molds were removed and then baked to insure the max. hardness. The molds were then sanded to remove any imperfections in the molds.

Section 2.3 Test Instrumentation

The test equipment used was a MATERIAL TESTING SYSTEM (MTS) of the Materials Testing Laboratory of the University of Calgary. The MTS was equipped with a plotter for recording the applied load versus displacement.

A HP 9816 computer outfitted with with a INFOTEK A/D scanner was used to record applied load, displacement, and strain. A Vishay 2110 amplifier was used to amplify the strain gauge output.

Section 3. Test Results

Section 3.1 Test 1 Results

The object of this test was to study the material properties and compare the measured displacement with the displacement calculated from the measured strain.

The test results show the rubber has a dual Modulus. One from 0 to 25 psi a non-linear Modulus and above 25 psi to 120 psi.

Three pretests were performed with an increasing load and then three tests from 0 to 120 psi were conducted. A value of 120 psi as the max. pressure was chosen as this represents a pressure well above the expected values in the bearing installation.

Section 3.2 Test 2,3,4 Results

These tests were designed to study the performance of the bearing under cyclic loadings. A base load was applied and then a Haversine loading was then imposed at varies frequencies (0.5, 1.0, 2, 4, 8 Hz). This range of frequency expected on the bearings. A frequency of 8 Hz represents a shaft turning at 120 Rpm with 4 bladed prop constantly milling.

Test 2 was conducted in the linear modulus region with a initial pressure of 38 psi and a max. of 63 psi.

Test 3 was conducted in the nonlinear modulus region with a initial pressure of 2.5 psi and a max. of 25 psi.

Test 4 was conducted in both the nonlinear and linear modulus region with a initial pressure of 2.5 psi and a max. of 120 psi.

Section 3.3 Test 5 Results

This test was designed to study a single sharp load of the bearing. A initial pressure of 2.5 psi was applied and then a displacement was specified which created a pressure of 170 psi.

Two test of this type were performed, in the first test the displacement (load) lasted for 0.05 seconds and in the second 0.10 seconds. This test shows the bearing response lags the instantaneous displacement/load.

Section 3.4 Test 6 Results

This test was designed to test the durability of the gauge installation under very high strains. This is to simulate the compression of the staves during installation.

When the load was applied a positive strain (tension) in the gauge was expected due to Poisson effect but under load the opposite occurred. This was due to sample alignment difficulties causing bending in the sample which induced compression in the gauge area. No further testing of this type was performed at this time.

Section 3.5 Test 7 Results

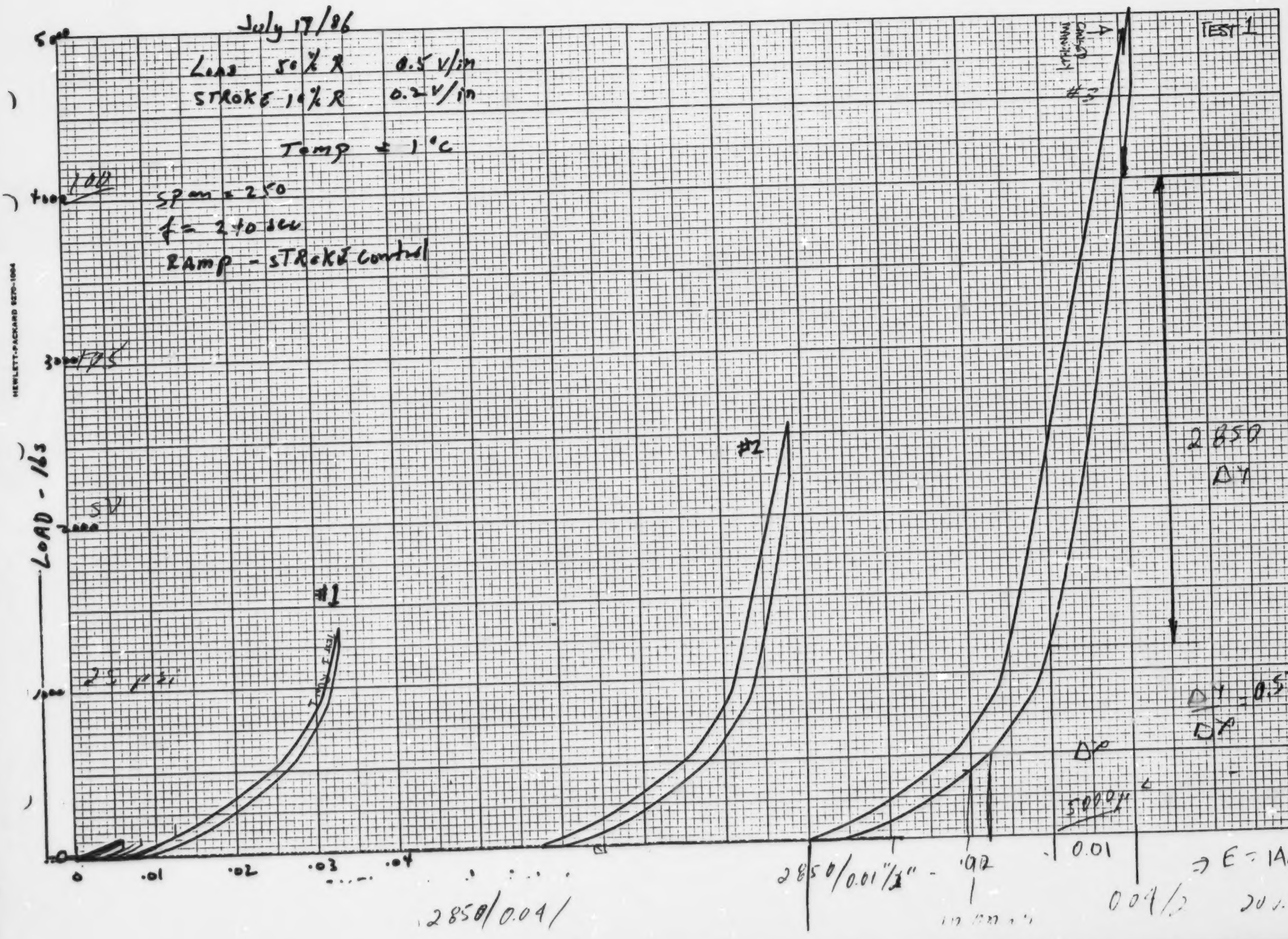
This test was to test the long term creep of the rubber material. The sample was loaded with a constant pressure of 37.5 psi and left for 8.5 hours. Over this time the temperature climbed from 1 deg. C to 11 deg. C. Over the 8.5 hours a creep of 0.030 inches occurred (1.5% strain). Upon release of the load a offset of 0.01 inch remained.

Section 3.6 Test 8 Results

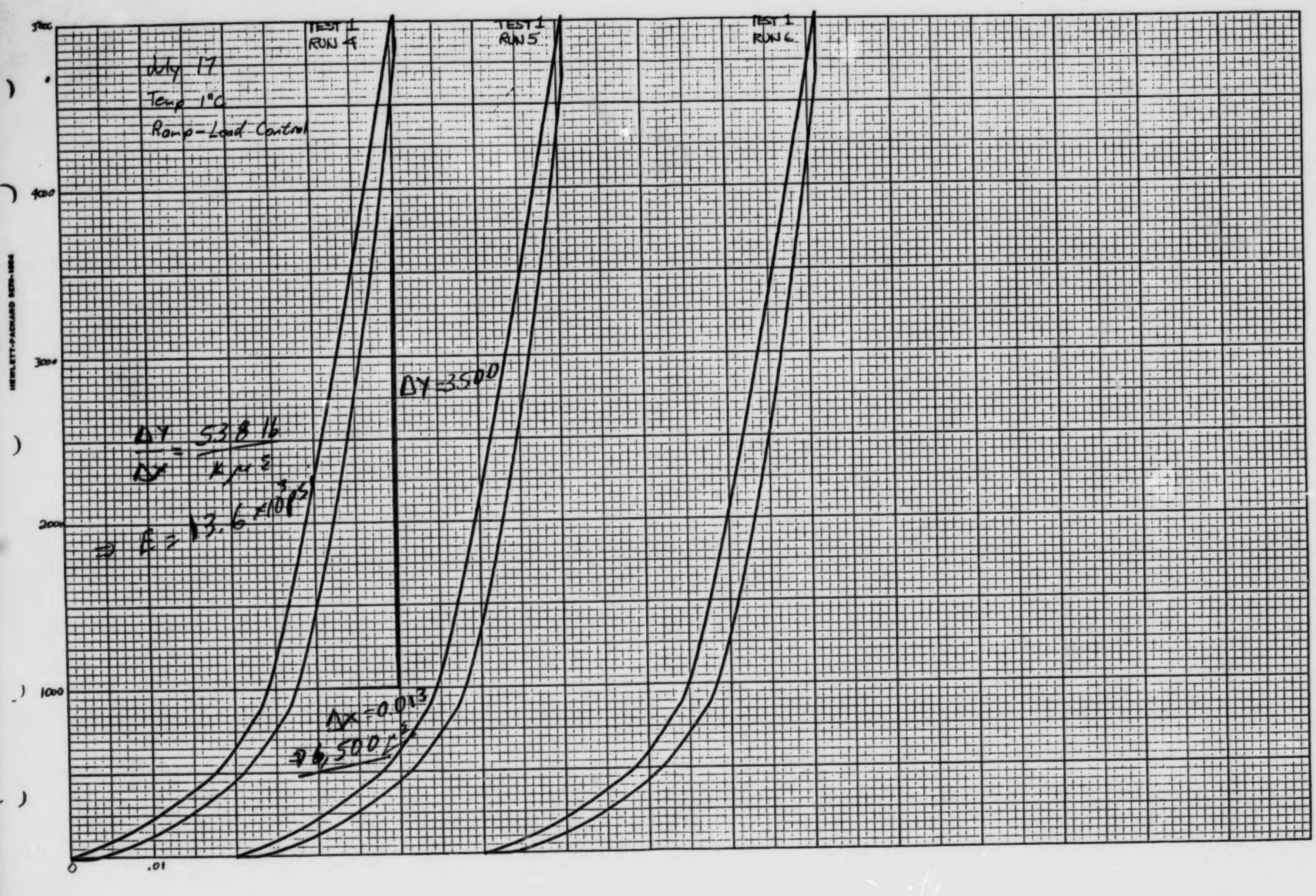
This test was designed to test the installation of the gauge when submerged in water. The sample was sealed in a pressure vessel filled with 3.5 % NaCl and 40 psi pressure was applied. The sample was left for 24 hours and then checked for changes in gauge resistance due to moisture penetration. No change was found.

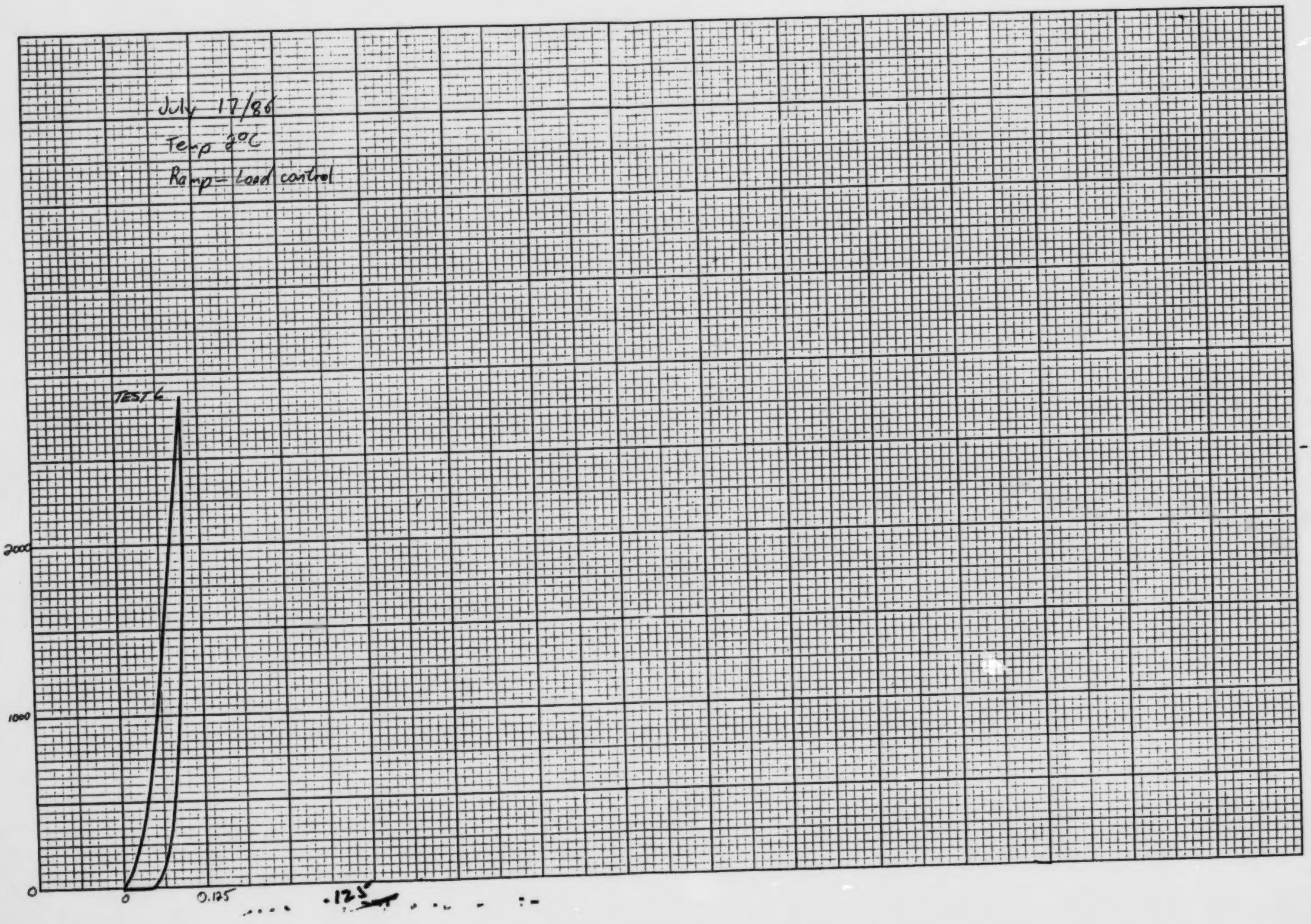
APPENDIX A

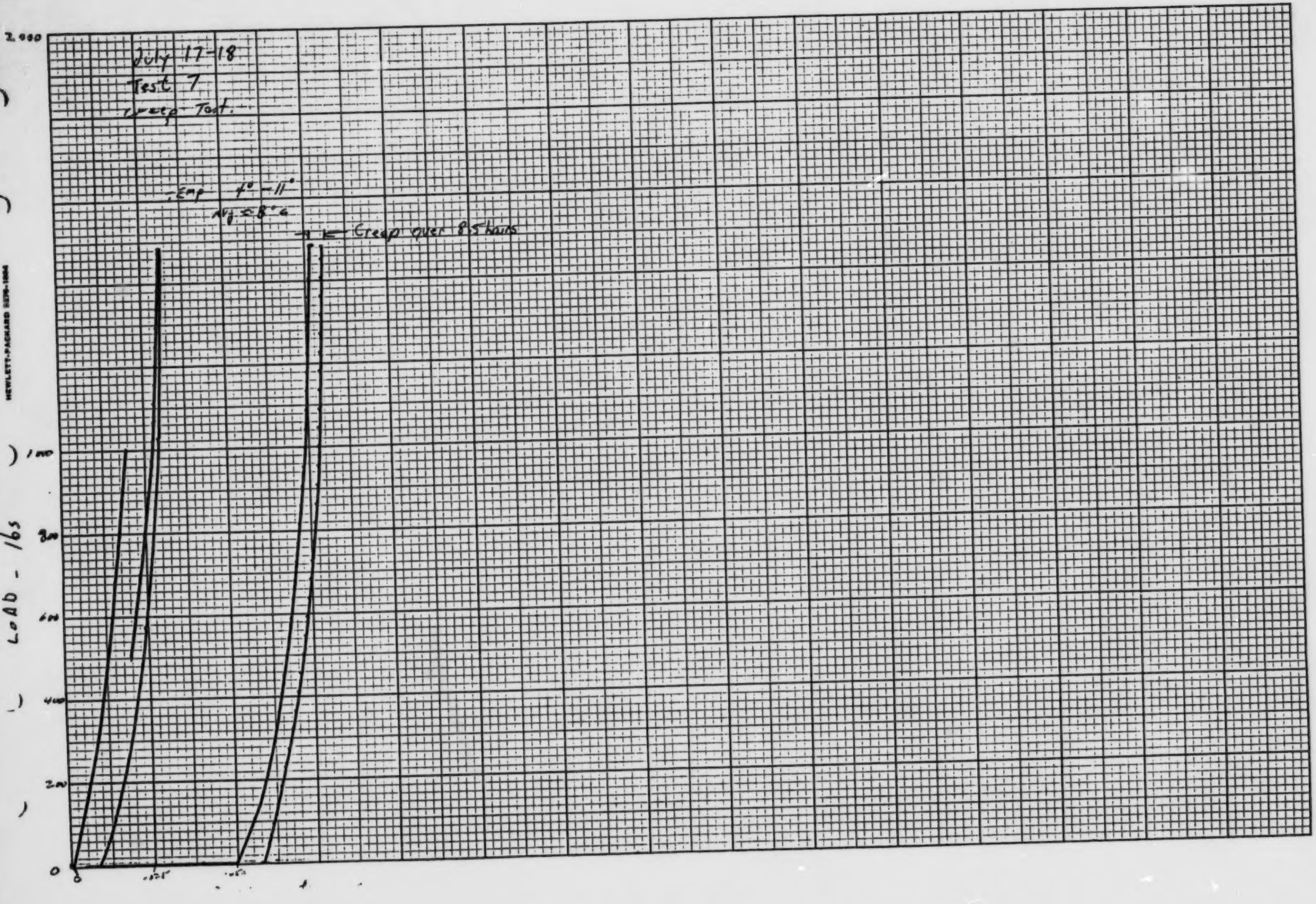
TEST RESULTS



HEWLETT-PACKARD 9270-1004


July 17
Temp 1°C
Ramp-Load Control
TEST 1 RUN 4
TEST 1 RUN 5
TEST 1 RUN 6
ΔY=3500
ΔY/ΔX = 538 lb / k μ ε
⇒ E ≈ 13.6 ×10³ psi
ΔX=0.013
⇒ 6,500 με
5000
4000
3000
2000
1000
0
.01
HEWLETT-PACKARD 9270-1004


July 17/86
Temp 2°C
Ramp = Load control
TEST 6
2000
1000
0
0
0.125
.125



July 17-18
Test 7
Creep Test.

Temp 4° – 11°
Avg ≈ 8° c

← Creep over 8.5 hours

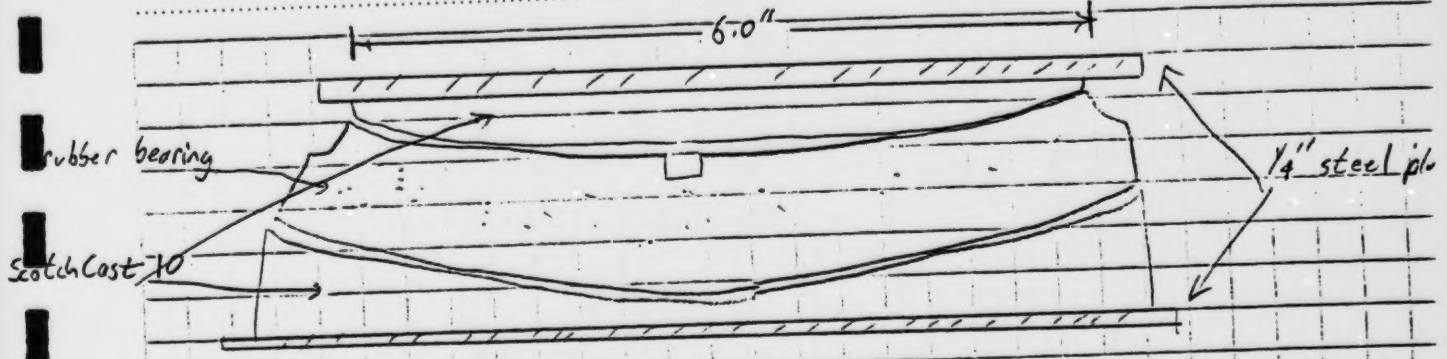
APPENDIX B

WORKING NOTES

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

SHEET 1 OF 7
DATE July 17/8
BY RA/JG
CH'K. BY

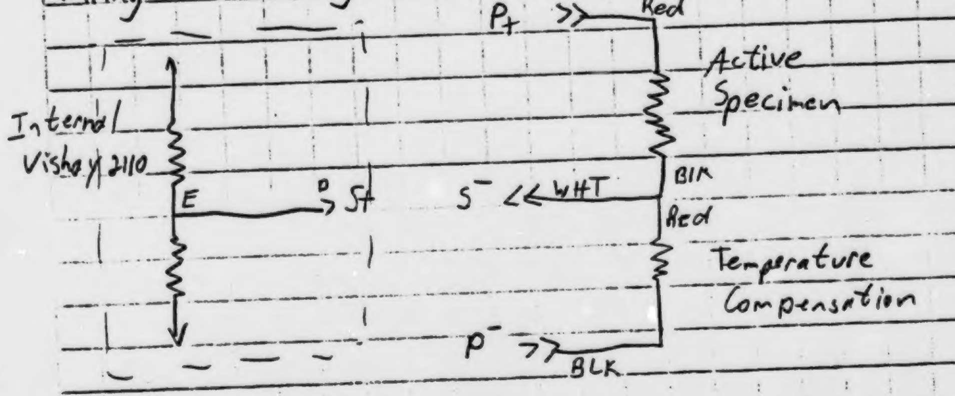
JOB. NO. 2452
PROJECT
SUBJECT Compression Test of Rubber STave



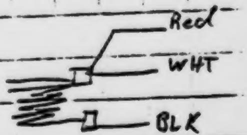
Area of upper platten 6.0 x 6.6 = 39.6 in^2

at	100 psi	Load = 3958 lbs
	120 psi	Load = 4750
	150 psi	Load = 5940
	40 psi	Load = 1583

Wiring of Gauge



Specimen Read negati
when specimen compr



ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT
SUBJECT Compression Test of Rubber Stove

SHEET 2 OF 7
DATE July 17/86
BY AA/JG
CH'K. BY

Calibration Factors for input into Software

Loading Ram of Mst

Signal output 10 volts = 10,000 lbs

$$\text{Input\_calib} = \frac{1}{\left(\text{Eng\_Calib} \times \text{Exitation} \times \frac{\text{Gain}}{1000}\right)}$$

$$= \frac{1}{\frac{10{,}000}{10} \times 1\,\text{v} \times \frac{1000}{1000}} = 1 \times 10^{-3}\ \text{mv/v/lb}$$

Displacement of Loading Ram

signal output 10 volts = 0.5 in

$$\text{Input\_calib} = \frac{1}{\left(\frac{0.5}{10} \times 1 \times \frac{1000}{1000}\right)} = 20\ \text{mv/V/in}$$

Strain Gauge

G.F = 2.06 , Number Active arms = 1

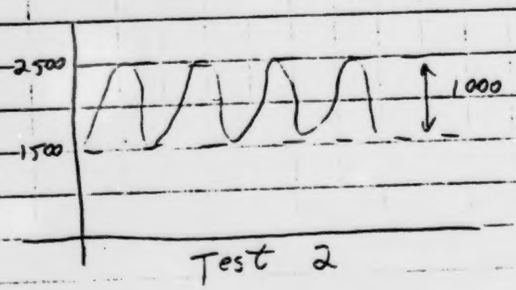
$$\text{Input calib} = \frac{2.06}{4} \times 1000 = 5.15 \times 10^{2}\ \text{mv/v/}\varepsilon$$

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

SHEET 3 OF 7
DATE July 17
BY RR./J.G.
CH'K. BY

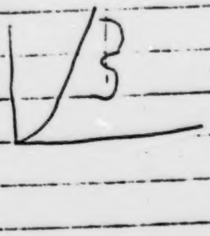
JOB. NO. 2452
PROJECT
SUBJECT Compression test of Rubber Staves

TEST	Run	Gain	Ex (Volts)	Min. Load	Max. Load (lbs)	Displacement in	Temperature °C	Description
1	1	300	1	0	1370	0.026	0°	Ramp
1	2	300	1	0	2560	0.030	0°	Ramp
1	3	2000	1	0	4900	0.0415	0°	Ramp
1	4	2000	1	0	5000	–	0°	Ramp
1	5	2000	1	0	5000	–	0°	Ramp
1	6	2000	1	0	5000	–	0°	Ramp
2	1	2000	1	1496	2502	–	1°	0.5 Hz Haversine
2	2	2000	1	1494	2502	–	1°	1.0 Hz Haversine
2	3	2000	1	1494	2502	–	1°	2.0 Hz Haversine
2	4	2000	1	1494	2502	–	1°	4.0 Hz Haversine
2	5	2000	1	1494	2502	–	1°	8.0 Hz Haversine



Test 2

Test 2 in linear region of Load vs. displacement curve and load limited



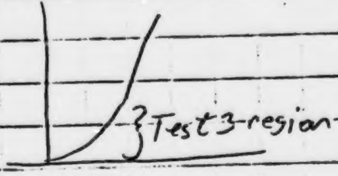
ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT
SUBJECT Compression of Rubber Stave

SHEET 4 OF 7
DATE July 17/86
BY AA/JG
CH'K. BY

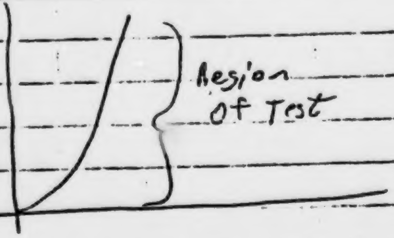
Test	Run	Gain	Ex (Volts)	Min. Load (lb)	Max. Load (lb)	Temp. °C	Description
3	1	2000	1	102	1006	1	0.5 Hz Haversine
3	2	2000	1	102	1008	1	1 Hz Haversine
3	3	2000	1	102	1008	1	2 Hz Haversine
3	4	2000	1	102	1010	1	4 Hz Haversine
3	5	2000	1	102	1015	1	8 Hz Haversine

Test 3 in non-linear region
and load limited



Test	Run	Gain	Ex	Min. Load	Max. Load	Temp	Description
4	1	2000	1	100	5001	2°	0.5 Hz Haversine
4	2	2000	1	112	5003	2	1 Hz Haversine
4	3	2000	1	100	5005	2°	2 Hz Haversine
4	4	2000	1	102	5004	2°	4 Hz Haversine
4	5	2000	1	102	5013	2°	8 Hz Haversina

Test 4 in overal region 100-5000 lbs and load Limited



ARCTEC CANADA LIMITED

ENGINEERING DESIGN CALCULATIONS

SHEET 5 OF 7

JOB. NO. 2452

DATE

PROJECT

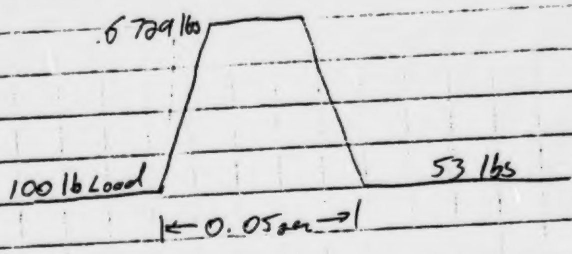
BY

SUBJECT Compression Test of Rubber Stave

CH'K. BY

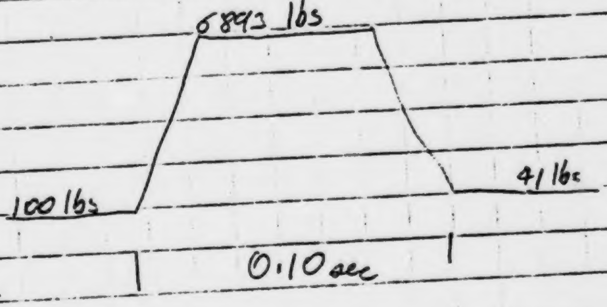
TesT 5 TransienT Response

TesT 5 Run 1



Note: displacement limited

TesT 5 Run 2



Note: displacement limited

$\varepsilon = \frac{\Delta L}{\ell} =$ 1000#

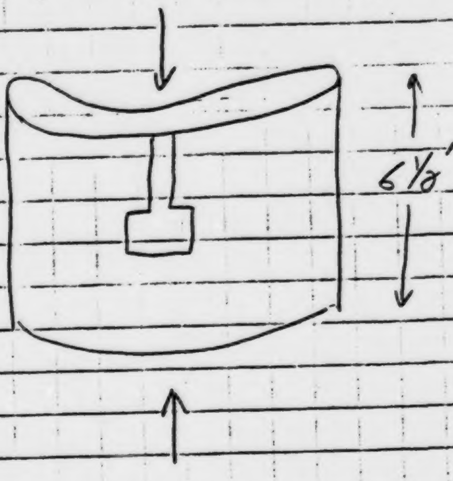
$\Delta L =$ 2000#

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT
SUBJECT Compression of Rubber Stave

SHEET 6 OF 7
DATE July 17/86
BY Af/DC
CH'K. BY

TesT 6 Longitidinal Loading



Test 1

Gain =400 Ex-1 Volts

for displacement of 0.1in = 1.5% strain gauge reads a negative (co
value rather than expected positive (tension) due to loading conditions

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT
SUBJECT Compression of Rubber Stave

SHEET 7 OF 7
DATE July 17
BY Ron/JG
CH'K. BY

Test 7 long term Creep test

July 18 1:00 — 1487 lb of constant load at 2°C
Voltage from strain gauge at 2000 gain 1 volt Ex
was −1.018 volts

July 18 9:30 1487 lb of load at 11°C
Voltage from strain gauge at 2000 gain 1 volt Ex
was = −.976 volts
Creep = 0.030"

July 18 9:35 No Load
Voltage from strain gauge −0.529 Volts

Permanent set ≅ .01 inch

Test 8 Water test

- Sample placed July 18 9:30 am into pressure vessel containing 3.5% NaCl solution
- 40 psi pressure applied

- July 19 1200 sample removed resistance check shows no leakage

APPENDIX C

Static Alignment Measurements and Calculations

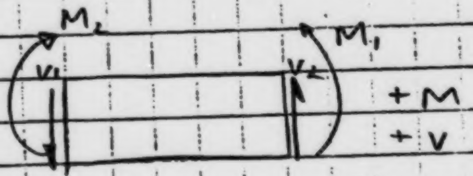
Data and Equations Used to Calculate Bearing Reactions

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

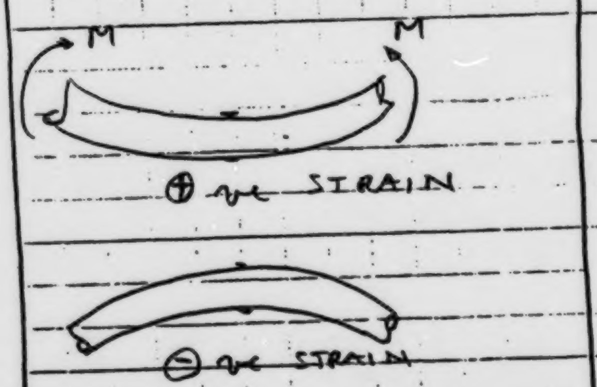
JOB. NO. 2452
PROJECT M.V. KARVIK PROP. TESTS
SUBJECT BENDING STRAIN MEASUREMENTS

SHEET 1 OF 1
DATE 87/01/27
BY ONBL
CH'K. BY

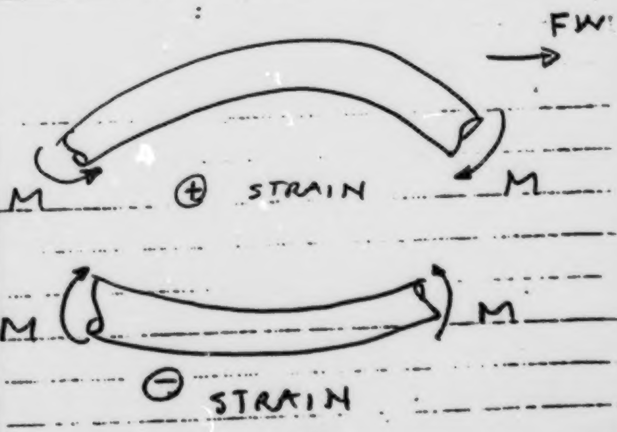
GAUGE LABEL	AUGUST 9, 1986 STRAIN ($\mu\varepsilon$)		SEP. 15, 1986 STRAIN $\mu\varepsilon$	
	VERTICAL	TRANS.	VERTICAL	TRANS.
SB 36	- 4.5	-2.2	4.0	-0.5
SB 39	-21.5	-3.1	-21.3	-3.0
SB 47	-6.7	-6.5	-7.0	-6.5
SB 56	0.8	-9.0	0.75	-9.8
SB 63	14.9	+3.4	14.5	+3.1



SHEAR / BENDING SIGN CONVENTION



LOOKING TO PORT



- PLAN VIEW

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT M.V. KALVIK
SUBJECT SHAFT ALIGNMENT EQUATIONS

SHEET 1 OF
DATE [illegible]
BY [illegible]
CH'K. BY U

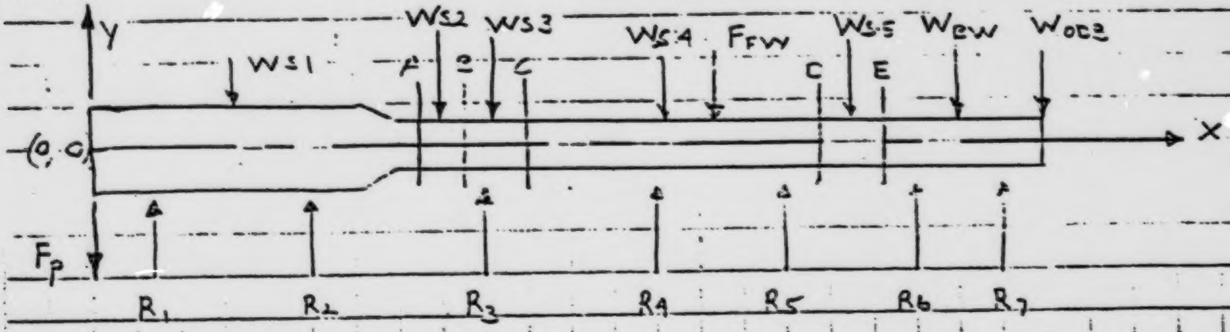
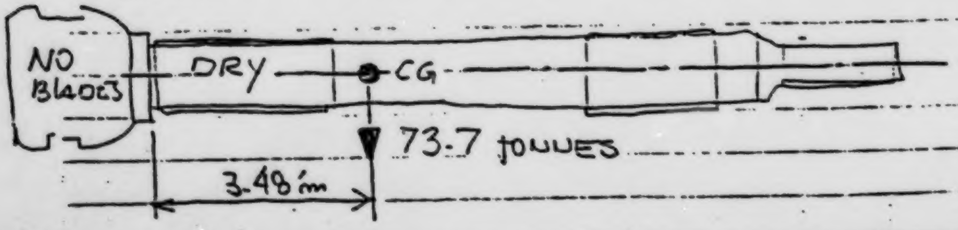


FIGURE 1 - SHAFT LOAD SCHEMATIC

F_p = PROPELLER WEIGHT IN WATER
F_{FW} = WEIGHT OF FLYWHEEL
R_{BW} = WEIGHT OF BULL WHEEL
R_{OCB} = WEIGHT OF C.O. BOX
W_{S1} = WEIGHT OF SHAFT SECTION $\overline{OA}$ =
W_{S2} = " " " " $\overline{AB}$ =
W_{S3} = " " " " $\overline{BC}$ =
W_{S4} = " " " " $\overline{CD}$ =

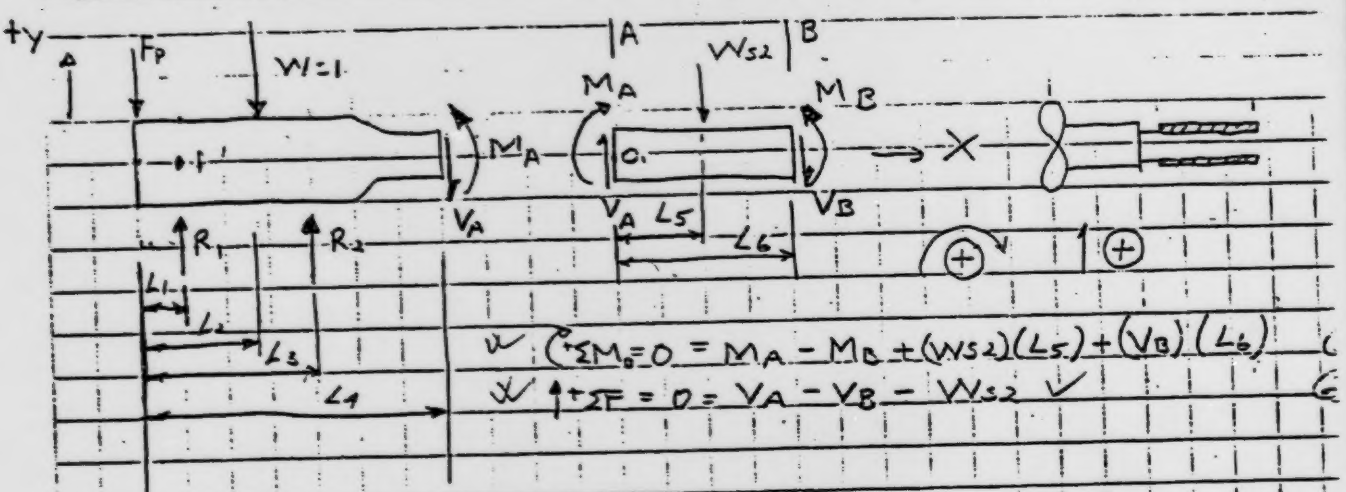
R_1 = AFT STERN TUBE BEARING LOAD
R_2 = FWD " " " "
R_3 = FRAME 41 BEARING LOAD
R_4 = FRAME 50 BEARING LOAD
R_5 = FRAME 55 BEARING LOAD
R_6 = FIRST GEAR BEARING LOAD
R_7 = SECOND GEAR BEARING LOAD



JOB. NO. 2452
PROJECT M.V. NALVIK
SUBJECT SHAFT ALIGNMENT EQUATIONS

SHEET 2 OF 9
DATE 26/08/2
BY D.N.B.C.
CH'K. BY K

AFT STERN TUBE BEARING [R_1, R_2] (SEE FIGURE 1)



✓ $\curvearrowright^{+}\Sigma M_0 = 0 = M_A - M_B + (W_{S2})(L_5) + (V_B)(L_6)$

✓ $\uparrow^{+}\Sigma F = 0 = V_A - V_B - W_{S2}$ ✓

✓ $+\uparrow \Sigma F_y = 0 = -F_p + R_1 + R_2 - W_{S1} - V_A = 0$ ③

✓ $\curvearrowright^{+}\Sigma M_1 = 0 = (-F_p)(L_1) + (W_{S1})(L_2 - L_1) - (R_2)(L_3 - L_1) + (V_A)(L_4 - L_1) - M_A$ ④

✓ ② $\Rightarrow$. $V_A = V_B + W_{S2}$ ⑤ $\leftarrow V_A$

✓ ① $\Rightarrow$. $V_B = [M_B - M_A - (W_{S2})(L_5)] / L_6$. ⑥ (MEASURED) $\leftarrow V_B$

✓ ④ $\Rightarrow$. $R_2 = \left[(-F_p)(L_1) + (W_{S1})(L_2 - L_1) + (V_A)(L_4 - L_1) - M_A\right] / (L_3 - L_1)$ ⑦ $\leftarrow R_2$

✓ ③ $\Rightarrow$. $R_1 = V_A + W_{S1} + F_p - R_2$ ⑧ $\leftarrow R_T$

√ $V_B \rightarrow V_A \rightarrow R_2 \rightarrow R_1$ CALCULATION ORDER

JOB. NO. 2452
PROJECT
SUBJECT SHAFT ALLIGNMENT EQUATIONS
SHEET 3 OF [illegible]
DATE 86/08/0
BY ANBL
CH'K. BY VL

✓ $V_B = [M_B - M_A - (W_{s2})(L_5)] / L_6$ ⑥ $\leftarrow V_B$

✓ $M_A = (\Sigma_A)(I_A)(E) / Y_A$ $\leftarrow M_A$

Σ_A = MEASURED [SB 38] (STRAIN)
$I_A = (\pi/64)(D_o^4 - D_i^4) = (\pi/32)(0.55^4 - 0.19^4)$ in [illegible]
$I_A = 4.428 \times 10^{-3}\ m^4$
$Y_A = 0.275\ m$
$E = 2.1 \times 10^{11}\ N/m^2$

✓ $M_B = (\Sigma_B)(I_B)(E) / (Y_B)$ $\leftarrow M_B$

Σ_B = MEASURED [SB 29] (STRAIN)
$I_B = (\pi/64)(D_o^4 - D_i^4) = (\pi/32)(0.47^4 - 0.19^4)$ in [illegible]
$I_B = 2.33 \times 10^{-3}\ m^4$
$Y_B = 0.235\ m$
$E = 2.1 \times 10^{11}\ N/m^2$

$W_{s2} \doteq (\rho)(A_{s1})(L_6)(9.81)$

$\rho = 7800$
$A_{s1} = (\pi/4)(D_o^2 - D_i^2) = (\pi/4)(0.77^2 - 0.19^2)$
$A_{s1} = 0.437\ m^2$
$L_6 = 1.64$

$W_{s2} = (7800)(0.437)(\cancel{1.64})(9.81) = 0.0548 \times 10^6\ N$ $\leftarrow W$

✓ $L_5 =$ (821.7 mm) $\leftarrow$

✓ $L_6 =$ (1643.4 mm) $\leftarrow L$

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SUBJECT SHAFT ALIGNMENT EQUATIONS

SHEET 4 OF 9
DATE 26/08/02
BY D.M.B.C
CH'K. BY V

✓ $V_A = V_B + W_{S2} = V_B + 0.0542 \times 10^6$ [N] — VA

✓ $R_2 = [(-F_P)(L_1) \pm (W_{S1})(L_2 - L_1) \pm (V_A)(L_4 - L_1) - M_A] / (L_3 - L_1)$ — R2

$F_P = (30649)(9.81) = 0.301 \times 10^6$ N — Fp

L_1 (STATIC) = 2.03 m — L1 (St
L_1 (DYNAMIC) = 2.30 m — L1 (D
$L_2 = (13.5 - 0.76)/2 = 6.37$ m — L2

$L_3 = 9.238 + 1.270 + .760 = 11.27$ m — L3

$L_4 = 0.76 + 13.94 - 1.055 - 0.12 = 13.50$ m — L4

$W_{S1} = (46765)(9.81) - W_{S2} =$ ~~0.451×10^6 N~~ — WS1
0.451×10^6 N

$M_A = (Z_A)(I_A)(E) / Y_A$ (AS IN PAGE 3) — MA

✓ $R_1 = V_A + W_{S1} + F_P - R_2$ — R1

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SHEET 5 OF 9
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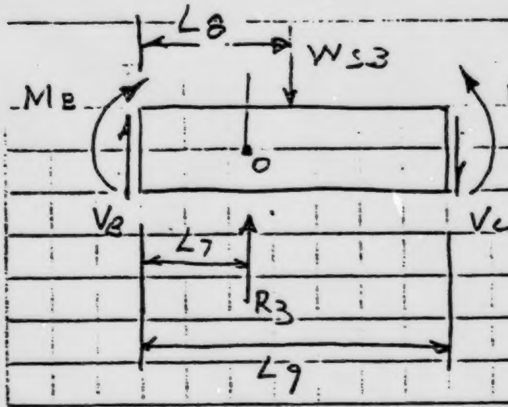
FIRST INTERMEDIATE BEARING (FRAME 41) [R3] (SEE FIGURE 1,



✓ $\overset{\curvearrowleft}{+}\sum M_O = 0 = M_B + (W_{s3})(L_8 - L_7) + (V_c)(L_9 -$
$+ V_B \cdot L_7 - M_C$

✓ $\overset{\curvearrowleft}{+}\sum M_o = 0 = M_B + (W_{s3})(L_8 - L_7) + (V_c)(L_9 - L_7) - M_c + (V_B)(L_7) = 0$ ⑨

✓ $+\uparrow \sum F = 0 = V_B - V_c + R_3 - W_{s3} = 0$ ⑩

Vc ←

✓ ⑨ $\Rightarrow V_c = \left[-M_B - (W_{s3})(L_8 - L_7) + M_c - (V_B)(L_7)\right] / (L_9 - L_7)$ ⑪

✓ ⑩ $\Rightarrow R_3 = W_{s3} + V_c - V_B$ ⑫

MB ←

$M_B =$ (AS BEFORE)

$W_{s3} = \rho A L (9.81)$

$\rho = 7800$ Kg

$A = (\pi/4)(D_o^2 - D_i^2) = (\pi/4)(0.47^2 - 0.19^2) = 0.145 m^2$

$L_9 = 3.402$ 3.402

Ws ←

$W_{s3} = 0.03775 \cancel{\times 10^6}$ N

L; ←

$L_7 = 0.587$ m

L8 ←

$L_8 = 1.701$ m

L9 ←

$L_9 = 3.402$ m

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JOB. NO. 2AS 2
PROJECT M.V. KALVIK
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BY D.N.B./V.L.
CH'K. BY VL

M_C

$M_C = (\mathcal{E}_C)(I_C)(E)/Y_C$

$\mathcal{E}_C$ = MEASURED [SB 47] (STRAIN)
$I_C = I_B = 4.66 \times 10^{-3}\ m^4$
$E = 2.1 \times 10^{11}\ N/m^2$
$Y_C = 0.235\ m$

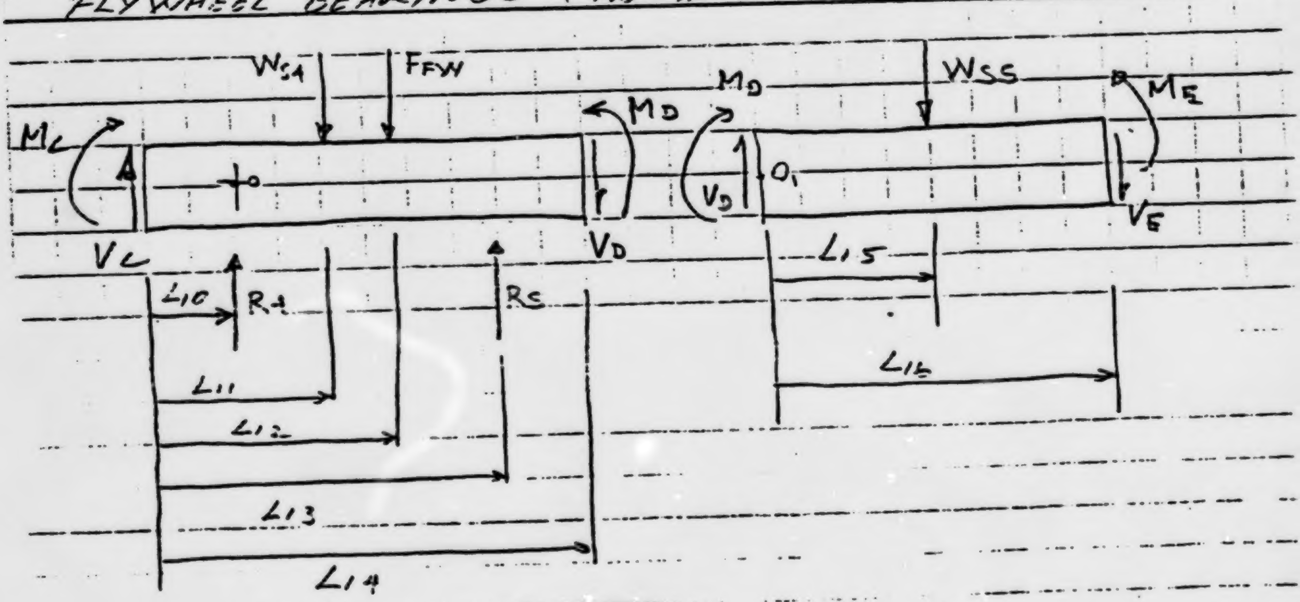
V_B

✓ V_B = AS BEFORE

R_3

✓ $R_3 = W_{S3} + V_C - V_B$

FLYWHEEL BEARINGS (FRAME 50-55) R_4 & R_5 (SEE FIGURE 1



✓ $\overset{\curvearrowleft}{+} \Sigma M_0 = 0 = M_C + (V_C)(L_{10}) + (W_{S4})(L_{11} - L_{10}) + (F_{FW})(L_{12} - L_{10}) - (R_5)(L_{13} - L_{10})$ (1
$+ (V_D)(L_{14} - L_{10}) - M_D$

✓ $+\uparrow \Sigma F = 0 = V_C - W_{S4} - F_{FW} + R_4 + R_5 - V_D$ (14)

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SUBJECT SHAFT ALIGNMENT EQUATIONS

SHEET 7 OF 9
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BY RJBC IV.L
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$\overset{+}{\curvearrowleft} \Sigma M_{D_1} = (W_{SS})(L_{15}) \pm (V_E)(L_{16}) - M_E \pm M_D$ ✓ ⑮

$+\uparrow \Sigma F_{D_1} = V_D - W_{SS} - V_E = 0$ ✓ ⑯

⑯ $\Rightarrow V_D = V_E + W_{SS}$ ✓ ⑰ $\leftarrow V_C$

⑮ $\Rightarrow V_E = [M_E - M_D - (W_{SS})(L_{15})] / L_{16}$ ✓ $\leftarrow V_E$

⑬ $\Rightarrow R_5 = [\pm M_C + (V_C)(L_{10}) + (W_{S4})(L_{11} - L_{10}) + (F_{FW})(L_{12} - L_{10}) + (V_D)(L_{14} - L_{10}) - M_D] / (L_{13} - L_{10})$ ✓ ⑱ $\leftarrow R$

⑭ $\Rightarrow R_4 = -V_C + W_{S4} + F_{FW} - R_5 + V_D$ ✓ ⑲ $\leftarrow R$

$M_E = (\varepsilon_E)(I_E)(E) / (Y_E)$ $\leftarrow M_E$

ε_E = MEASURED [SB 63] (STRAIN)
$I_E = 4.66 \times 10^{-3}\ m^4$
$E = 2.1 \times 10^{11}\ m^4$
$Y_E = 0.235$

$M_D = (\varepsilon_D)(I_D)(E) / (Y_D)$ $\leftarrow M_D$

ε_D = MEASURED [SB 56] (STRAIN

$W_{SS} = \rho AL(9.81) = (7860)(0.145)(\overset{3.039^{2}}{3.04})(9.81) = \overset{0.0337 \times 10^{6}}{\cancel{0.0337 \times 10}}$ N $\leftarrow W$

$L_{10} = 1.685\ m$, $L_{11} = 2.51\ m$, $L_{12}\ 3.19\ m$
$L_{13} = 4.19\ m$, $L_{14} = 5.04\ m$, $L_{15} = 1.52$, $L_{16} = 3.04\ m$ $\}\leftarrow L$

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ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2152
PROJECT M.V. KALVIK
SUBJECT SHAFT ALIGNMENT EQUATIONS

SHEET 8 OF 9
DATE 86/08/03
BY CN.ZC/V.L.
CH'K. BY VL

M.

$M_c = (\varepsilon_c)(I_c)(E)/Y_c$

ε_c = MEASURED [SB47] (strain)

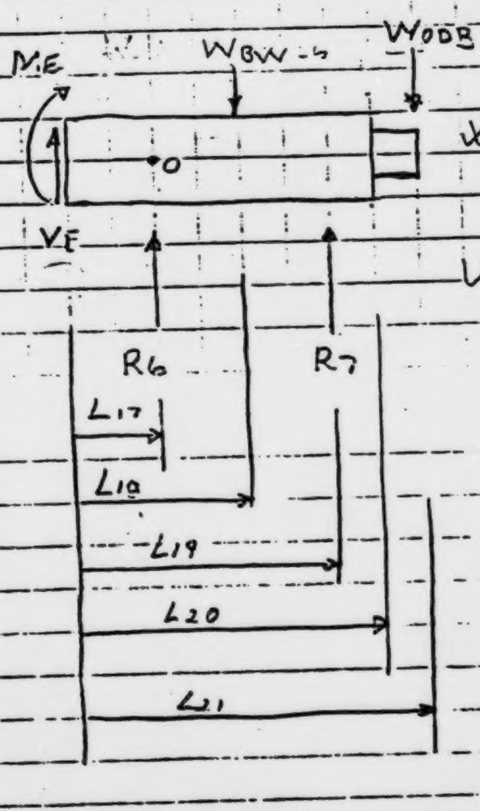
V_c = AS BEFORE

$W_{S4} = \rho A L(9.81) = (7800)(0.145)(5.842)(9.81) = 0.05594 \times 10^6$ N

E_{FW}

$F_{FW} = (12000)(9.81) = 0.1177\ 10^6$

GEAR BEARINGS (R6 + R7)



✓ ↺ $+\Sigma M = 0 = M_E + (V_E)(L_{17}) + (W_{BW})(L_{18} - L_{17})$
$+ (W_{OD})(L_{21} - L_{17}) - (R_7)(L_{19} - L_{17})$

✓ ↑ $+\Sigma F = 0 = V_E + R_6 + R_7 - W_{BW} - W_{ODB}$ (2

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PROJECT M.V. KALVIK
SUBJECT SHAFT ALIGNMENT EQUATIONS

SHEET 9 OF 9
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✓

$$⑳ \Rightarrow R_7 = \left[M_E + (V_E)(L_{17}) \overset{-(W_{SB})(L_{17}-L_{22})}{+} (W_{2W})(L_{18}-L_{17}) \pm (W_{OD})(L_{21}-L_{17})\right] / (L_{19}-L_{17})$$

$$⑲ \Rightarrow R_6 = W_{2W} \pm W_{OD8} - V_E - R_7 \quad ✓✓$$

M_E - AS BEFORE
V_E - AS BEFORE

$L_{19} - L_{17} = 1.035$ m
$L_{21} - L_{20} = 0.522$ m
$L_{20} = 3.50$ m
$L_{21} = 1.026$ m
$L_{17} = -0.44 + 2.48 = 2.04$ m $= L_{17}$
$L_{19} = 1.035 + 2.04 = 3.075 = L_{19}$
$L_{18} = L_{17} + (1.035)/2 = 2.04 + 0.52 = 2.56 = L_{18}$

$\leftarrow L_{17}-L_2$

$W_{BW} = (5660)(9.81) + (7800)(0.145)(3.27)(9.81) = 0.0918 \times 10^6$ N $\leftarrow$

$W_{OD} = (915)(9.81) = 0.00895 \times 10^6$ N

$\leftarrow W_{OD8}$

```
STATIC BEARING REACTIONS ON M.V. KALVIK
FILE NAME 4POS3
                                                             SHEAR
POSITION                     BENDING MOMENT                  [MN]
                                 [MNm]
                                                             -.009
                                  .015                       -.064
SB36                             -.045                        .009
SB39                             -.014                        .027
SB46                              .002                       -.007
SB56                              .031
SB63


BEARING                    VERTICAL REACTION          TRANSVERSE REACTION
                                 [MN]                         [MN]

                                                              -.001
AFT STERN TUBE                    .628                         .003
FWD. STERN TUBE                   .115                        -.005
1st. INT.                         .111                         .001
2nd. INT.                         .066                         .010
3rd. INT.                         .125                        -.031
AFT GEAR                          .039                         .023
FWD. GEAR                         .069

                                                              0.000
SUM OF REACTIONS (MN)=           1.153

SUM OF SHAFT WEIGHTS (MN)        1.153


ALIGNMENT DATE  :  4 Aug 1986
CALCULATION DATE: 28 Jan 1987


CALCULATED OFFFSETS

     BEARING                 mm

AFT STERN TUBE             -60.5
FWD. STERN TUBE            -13.6
1st. INT.                    8.8
2nd. INT.                   29.1
3rd. INT.                   39.0
AFT GEAR                    58.9
FWD. GEAR                   62.0
```

```
STATIC BEARING REACTIONS ON M.V. KALVIK
FILE NAME STAT_22

POSITION                   BENDING MOMENT              SHEAR
                               [MNm]                    [MN]

SB36                            .014                    -.007
SB39                           -.044                    -.062
SB46                           -.015                     .009
SB56                            .002                     .026
SB63                            .030                    -.007


BEARING                  VERTICAL REACTION        TRANSVERSE REACTION
                               [MN]                      [MN]

AFT STERN TUBE                  .628                    0.000
FWD. STERN TUBE                 .117                    -.003
1st. INT.                       .109                     .001
2nd. INT.                       .067                    -.002
3rd. INT.                       .124                     .013
AFT GEAR                        .040                    -.033
FWD. GEAR                       .068                     .024

SUM OF REACTIONS (MN)=         1.153                    0.000

SUM OF SHAFT WEIGHTS (MN)      1.153


ALIGNMENT DATE  : 15 SEP 1986
CALCULATION DATE: 28 Jan 1987


CALCULATED OFFFSETS

     BEARING              mm

AFT STERN TUBE          -60.4
FWD. STERN TUBE         -13.6
1st. INT.                 8.8
2nd. INT.                29.1
3rd. INT.                39.0
AFT GEAR                 58.9
FWD. GEAR                62.0
```

Detailed Error Calculation

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452 C
PROJECT MV KALVIK
SUBJECT Error Analysis - Formulations

SHEET 1 OF 8
DATE Jan 5, 87
BY CST
CH'K. BY

Parameters affecting the accuracy of moment determination include:

1.) gage misalignment
2) gage factor variation
3) instrumentation sensitivity
4) physical properties and dimensions

Error in moment as suggested by Forrest and Labosky (Marine Tech. vol 18, No3 Jul 1981) is given as

$$m = \frac{EI}{c}\left\{(1-\cos 2\alpha)\frac{\varepsilon_a(1-\nu)}{2} \pm 0.005\,\varepsilon_a \pm \frac{1}{CF}\times 10^{-6} \pm 0.02\,\varepsilon_a\right\}$$

where E = Elastic modulus $= 2.1 \times 10^{11}$ N/m²
I = shaft moment of inertia $= \pi d^4/64$
c = shaft radius
α = gage misalignment angle
ν = Poisson's ratio
ε_a = axial strain
CF = circuit factor (= 2 for two-gauge configuration)

Assuming the gauge is positioned well (small α), then the moment error equation can be reduced to:

$$m = \pm 0.025\,\frac{EI\varepsilon_a}{c} \pm \frac{EI}{c\,CF}\times 10^{-6}$$

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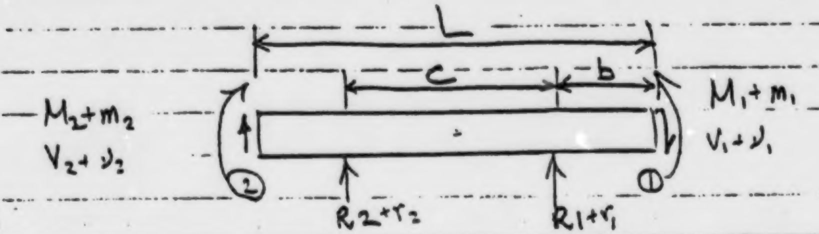
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452C
PROJECT
SUBJECT Error Analysis – formulations
SHEET 2 OF 9
DATE Jan 9, 1
BY
CH'K. BY



$$\Sigma M \text{ (about } R2) = 0 = (M_1 \pm m_1) - (M_2 \pm m_2) - (V_1 \pm \nu_1)(b+c) + (R_1+r_1)c - (V_2 \pm \nu_2)(L-b-c)$$

$$(R_1+r_1) = \frac{M_2 - M_1 + V_1(b+c) + V_2(L-b-c)}{c} + \frac{m_1 + m_2 + \nu_1(b+c) + \nu_2(L-b-c)}{c}$$

the 2nd term is resulted from adjusting the signs of various error components for the worst case.

$$\Sigma M \text{ (about } R1) = 0 = (M_1 \pm m_1) - (M_2 \pm m_2) - (V_1 \pm \nu_1) b - (R_2+r_2) c - (V_2 \pm \nu_2)(L-b)$$

$$(R_2+r_2) = \frac{M_1 - M_2 - V_1 b - V_2 L}{c} + \frac{m_1 + m_2 + \nu_1 b + \nu_2 (L-c)}{c}$$

signs of various error components in the 2nd term have been adjusted to reflect the worst case

Thus, the reaction errors are

$$r_1 = \frac{m_1 + m_2 + \nu_1(b+c) + \nu_2(L-b-c)}{c}$$

$$r_2 = \frac{m_1 + m_2 + \nu_1 b + \nu_2(L-b)}{c}$$

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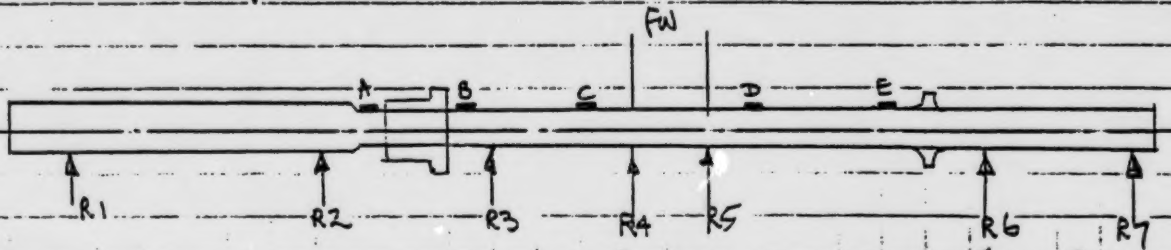
ENGINEERING DESIGN CALCULATIONS

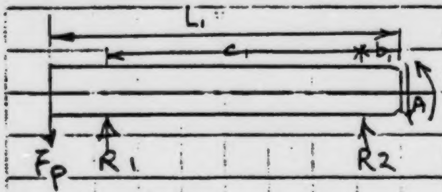
JOB. NO. 2452C
PROJECT M.V. KALVIK
SUBJECT Error Analysis - Formulations

SHEET 3 OF 8
DATE Jan 5, 87
BY G.T.
CH'K. BY



Reaction Errors

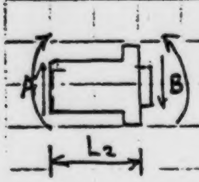
Shear Errors



$$r_1 = \frac{m_a + v_a b_1}{c_1}$$

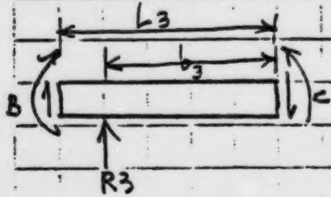
(require known v_a)

$$r_2 = \frac{m_a + v_a (b_1 + c_1)}{c_1}$$



none

$$v_a = v_b = \frac{m_a + m_b}{L_2}$$

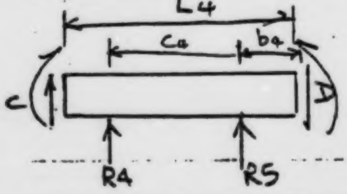


$L_3 - b_3 = 0.5'$

dia $= 0.4'$

$$r_3 = \frac{m_b + m_c + v_b L_3}{b_3}$$

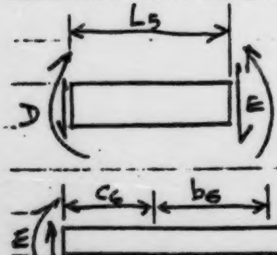
$$v_c = \frac{m_b + m_c + v_b (L_3 - b_3)}{b_3}$$



$$r_4 = \frac{m_c + m_d + v_d b_4 + v_c (L_4 - b_4)}{c_4}$$

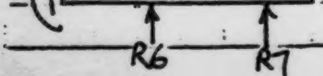
(require known v_c and v_d

$$r_5 = \frac{m_c + m_d + v_d (b_4 + c_4) + v_c (L_4 - b_4 - c_4)}{c_4}$$



none

$$v_d = v_e = \frac{m_d + m_e}{L_5}$$



$$r_6 = \frac{m_e + v_e (b_6 + c_6)}{b_6}$$

none

$$r_7 = \frac{m_e + v_e c_6}{b_6}$$

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ENGINEERING DESIGN CALCULATIONS

JOB. NO.
PROJECT
SUBJECT Error Analysis – Variable Definition.

SHEET 4 OF 2
DATE Jan 5, 87
BY
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Variable used in Error Analysis	Variable used in Shaft Alignment Eq.		Final Value
L_1	$= L4$	$= 13.47$	13.47
b_1	$= L4 - L3$	$= 13.47 - 11.27 =$	2.20
c_1	$= L3 - L1$	$= 11.27 - 2.03 =$	9.24
L_2	$= L6$	$= 1.64$	1.64
L_3	$= L9$	$= 3.402$	3.402
b_3	$= L9 - L7$	$= 3.402 - 0.588$	2.814
L_4	$= L14$	$= 5.042$	5.042
b_4	$= L14 - L13$	$= 5.042 - 4.185$	0.857
C_4	$= L13 - L10$	$= 4.185 - 1.685$	2.500
L_5	$= L16$	$= 3.039$	3.039
b_6	$= L19 - L17$	$= 3.075 - 2.04$	1.035
C_6	$= L17$	$= 2.04$	2.040
c_a	shaft radius at gauge A	0.275 m	0.275 m
I_a	moment of inertia	$\frac{\pi}{64}(.55^4 - .19^4)$	4.428×10^{-3}
Z_a	sectional modulus	I_a / c_a	1.610×10^{-2}
c_b	shaft radius at gauge B	0.235	0.235
I_b	moment of inertia	$\frac{\pi}{64}(.47^4 - .19^4)$	2.331×10^{-3}
Z_b	sectional modulus	I_b / c_b	9.721×10^{-3}
c_c	$\left.\begin{matrix} c_b \\ = I_b \\ Z_b \end{matrix}\right\} = \left\{\begin{matrix} c_d \\ I_d \\ Z_e \end{matrix}\right\}$		
I_c			
Z_c			

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO.
PROJECT
SUBJECT Error Analysis — Calc. for Reactions Before Drydock

SHEET 5 OF 8
DATE Jan 6/87
BY
CH'K. BY

Bending Strain Measurements — "98053"

		Vert. Bending με
SB36	gauge 1	+4.455
SB39	2	−21.475
SB46	3	−6.705
SB56	4	0.81
SB63	5	−14.89

Bending Moments Error Calculations:

$$\left.\frac{EI}{c}\right)_a = EZ\Big)_a = 2.1 \times 10^{11} \times 1.610 \times 10^{-2} \text{ m-N} = 3.381 \times 10^{9} \text{ m-N}$$

$$\left.\frac{EI}{c}\right)_b = \left.\frac{EI}{c}\right)_c = \left.\frac{EI}{c}\right)_d = \left.\frac{EI}{c}\right)_e = 2.1 \times 10^{11} \times 9.921 \times 10^{-3} \text{ m-N} = 2.083 \times 10^{9} \text{ m-}$$

The moment error equation is given as:

$$m = \pm 0.025 \frac{EI}{c} \varepsilon_a \pm \frac{EI}{c} \times 0.5 \times 10^{-6}$$

$$= \frac{EI}{c} \left(\pm 0.025\, \varepsilon_a \pm 0.5 \times 10^{-6} \right)$$

Thus:

	με	1st term	2nd term	(EI/c)	m (m-N)
Gage A (SB36)	−6.	0.1114×10^{-6}	0.5×10^{-6}	3.381×10^{9}	2067.143
B (SB39)	43.5	0.5369×10^{-6}	"	2.083×10^{9}	2159.863
C (SB46)	13.0	0.1676×10^{-6}	"	2.083×10^{9}	1390.611
D (SB56)	−1.0	0.0203×10^{-6}	"	2.083×10^{9}	1083.785
E (SB63)	27.0	0.3723×10^{-6}	"	2.083×10^{9}	1817.001

JOB. NO.
PROJECT
SUBJECT Error Analysis — Before Drydock

SHEET 6 OF 8
DATE Jan 6/87
BY J.T.
CH'K. BY

Shear Error Calculations:

$$v_a = v_b = \frac{m_a + m_b}{L_2} = \frac{2067.143 + 2157.863}{1.64} = 2577.443 \ (N)$$

$$v_c = \frac{M_b + M_c + v_b (L_3 - b_3)}{b_3} = \frac{2159.863 + 1390.611 + 2577.443(3.402 - 2.814)}{2.814}$$

$$= 1800.288 \ (N)$$

$$v_d = -v_e = \frac{m_d + m_e}{L_5} = \frac{1083.785 + 1817.001}{3.039} = 954.520 \ (N)$$

Reaction Error Calculations:

$$r_1 = \frac{m_a + v_a b_1}{c_1} = \frac{2067.143 + 2577.443 \times 2.2}{9.24} = 837.394 \ (N)$$

$$r_2 = \frac{m_a + v_a (b_1 + c_1)}{c_1} = \frac{2067.143 + 2577.443 \times (2.2 + 9.24)}{9.24} = 3414.837 \ (N)$$

$$r_3 = \frac{M_b + M_c + v_b L_3}{b_3} = \frac{2159.863 + 1390.611 + 2577.443 \times 3.402}{2.814} = 4377.731 \ (N)$$

$$r_4 = \frac{m_c + m_d + v_d b_4 + v_c (L_4 - b_4)}{c_4}$$

$$= \frac{1390.611 + 1083.785 + 954.520 \times 0.857 + 1800.288(5.042 - 0.857)}{2.5} = 4589.891$$

$$r_5 = \frac{m_c + m_d + v_d (b_4 + c_4) + v_c (L_4 - b_4 - c_4)}{c_4}$$

$$= \frac{1390.611 + 1083.785 + 954.520(0.857 + 2.5) + 1800.288(5.042 - 0.857 - 2.5)}{2.5} = 3484.88$$

ARCTEC CANADA LIMITED

ENGINEERING DESIGN CALCULATIONS

JOB. NO.

PROJECT

SUBJECT Error Analysis

SHEET 7 OF 8

DATE Jan 6 /8

BY

CH'K. BY

$$r_6 = \frac{M_e + V_e (b_6 + C_6)}{b_6} = \frac{1817.001 + 954.920 (1.035 + 2.04)}{1.035} = 4591.449 \ (N$$

$$r_7 = \frac{M_e + V_e C_6}{b_6} = \frac{1817.001 + 954.920 (2.04)}{1.035} = 3636.929 \ (N)$$

Error-bound Calculation Summary:

Gauge	Measured Moment (m-kN)	Moment Error (m-kN)	Shear (kN)	Shear Error (kN)
SB36	15.0	2.07	-9.0	2.58
SB39	-45.0	2.16	-64.0	2.58
SB46	-14.0	1.39	9.0	1.80
SB56	2.0	1.08	27.0	0.95
SB63	31.0	1.82	-7.0	0.95

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO.
PROJECT
SUBJECT Error Analysis — Before Drydock

SHEET 8 OF 8
DATE Jan 6/87
BY
CH'K. BY

Bearing	Vert. Reaction (kN)	Reaction Error (r) (kN)	r/R (%)
Aft Stern tube	628.0	0.84	0.13
Fwd Stern tube	115.0	3.41	2.97
Aft Intermed.	111.0	4.38	3.95
Aft Flywheel	66.0	4.59	6.95
Fwd Flywheel	125.0	3.48	2.78
Aft Gear	39.0	4.59	11.77
Fwd Gear	69.0	3.64	5.28

Notes :

- Errors are less than 3% for the stern tube bearings
- the high level of 12% is noted at the aft intermediate bea
  and it is probably attributed to the boundary effects of th
  support on the strain gauge SB39 which is about
  1.26 shaft diameter away from the bearing.

RECEIVED
JUN 27 1986

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Kelvik

RESEARCH & TECHNICAL ADVISORY SERVICES

Name of Ship or equivalent	BURRARD YARROWS 107 AND 554
Subject	ALIGNMENT AND LATERAL VIBRATION ANALYSIS
On behalf of	Burrard Yarrows Corporation, Vancouver.
Report No.	2090/583 HQ 10m 16/11/82
Copy No.	1
Date	November 1982.

Section Advanced Engineering Services.

Job No.

Contents

Summary
Page 2 Introduction
Description of Shafting
Page 3 Data and Assumptions used in the analysis
Page 4 Discussion of Vibration Analysis
Alignment

List of Appendices

APPENDIX 1 and 2
APPENDIX 3 - Tables 1 to 3
APPENDIX 4 - FIG. 1
APPENDIX 5 - Table 1
APPENDIX 6 - Alignment Procedure
APPENDIX 7 - Table 1

Lloyd's Register of Shipping

71, Fenchurch Street, London, EC3M 4BS

Report No. 2090/583

Name of Ship or equivalent BURRARD YARROWS 107/554

Subject Alignment and Lateral Vibration Analysis

Summary

This report details the alignment and lateral vibration analysis carried out on the main shafting of the above vessel.

The vibration analysis has found, using an estimated skeg stiffness of 40 tonnes/mm, that whirling occurs at a speed of 125 r.p.m., which is within ± 10% of the design running speed of 130 r.p.m.

If the shipbuilder's own structural analysis, or other tests, confirms this figure for skeg stiffness, then Classification will require vibration testing during trials.

The need for vibration testing can be avoided providing either,

a) a stiffness of the order of 80 tonnes/mm can be achieved

or b) a change to a 3 bladed propeller design is possible.

The alignment analysis has indicated possible unfavourable gear bearing loads, particularly when driving at less than full power with the inboard engines alone; therefore continuous running in this configuration cannot be recommended.

Written by		Approved by	
Name (typed)	N.A.Hall-Stride. B.Sc.	Name (typed)	T.F. Brock. B.Sc.
Signature	N.A.Hall-Stride	Signature	T.F.Brock
Designation	Surveyor	Designation	Principal Surveyor

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1. INTRODUCTION

The Society was requested by the Burrard-Yarrows Corporation, Vancouver to carry out the lateral vibration analysis of, and provide a vertical alignment procedure for, the main shafting of their twin screw ice-breaker Hull Nos. 107 and 554 which are being built to Class for the Owners, Gulf Canada Resources.

2. DESCRIPTION OF SHAFTING

The shafting was described by the plans listed in APPENDIX 1; from these the idealized shaft model used in the analysis and illustrated in APPENDIX 2, FIG.1, was produced.

The twin screw rotation directions are:-
Port - counterclockwise, starboard - clockwise; power being supplied by four S.W.D. diesel engines each of 4044 kW at 600 R.P.M. Two engines at equally disposed horizontal centres drive each shafting set via a "Lohmann and Stolterfoht" GVE.1500A gearbox at a maximum shaft speed of 130 R.P.M.

The shafting consists of:-

i) the gearshaft - supported radially on forward and after white metalled journal bearings, and axially by a thrust bearing. The gearshaft carries the C.P. propeller O.D. box of mass 915 kg at its forward end and the right hand helically cut main gear wheel of mass 5660 kg between the journal bearings. The gearshaft centre lies 710 mm above the horizontal mounting face of the gearbox.

ii) the forward intershaft - supported by a single L and S plummer bearing, and carrying the flywheel of mass 12000 kg on its after flange.

iii) the after intershaft - supported by two L and S plummer bearings.

iv) the tailshaft - having bronze shaft liners in way of the water lubricatec "Johnson Rubber" staved forward and after stern bearings, and carrying the LIPS 4 bladed C.P. propeller of mass 35027 kg.

The aft stern bearing is carried in a heavy cast boss, mounted in a built up plate skeg, effectively rigid in the vertical direction though flexible in the lateral direction.

3. DATA AND ASSUMPTIONS USED IN THE ANALYSIS

3.1 Propeller Data: The centre of gravity of the propeller was assumed to act at a point 760 mm aft of the tailshaft aft flange face. The mass data for the dry propeller and entrained water values as used in the vibration analysis are given in APPENDIX 3, TABLE 1. Also shown is the buoyancy force assumed to act on the propeller when fully immersed for the alignment procedure.

3.2 Tailshaft/Stern Bearing Data: The effective point of support of the rotating tailshaft in a long,water lubricated, rubber staved, aft stern bearing is uncertain. It has been traditionally assumed however, that the shaft will be supported at a point one third the length of the bearing from the aft edge when running, and at a point one quarter the length from the aft edge when stationary.

3.3 Gear Data: The main gear wheel mass, tooth angles and moment of inertia together with the tangential load exerted on the main wheel by each engine at full load are given in APPENDIX 3, TABLE 2.

The respective loads at the main gear wheel station for the three possible driving configurations are also given.

Thermal rise compensation for the gearshaft has been given as 0.234 mm by the manufacturers.

3.4 Flywheel Data: Mass and polar moment of inertia for the flywheel are given in APPENDIX 3, TABLE 3.

Continued/...

4. DISCUSSION OF VIBRATION ANALYSIS

The lateral mode of vibration is essentially dependent upon the lateral stiffness of the after stern bearing mounting skeg and the assumed point of support of the shaft in the aft bush. By considering a representative length of the skeg in way of the shaft support point, and treating it as a uniform cantilever extending from the hull line to the shaft centreline, a lateral stiffness of 40 tonnes/mm was estimated. Using this value of lateral stiffness and the traditional one third bearing length support point, then the predicted blade order whirling speeds for the first lateral mode are 125 r.p.m. and 123 r.p.m. for forward and reverse whirl respectively.

More complete results, illustrating the effect of the assumed aft stern bearing support point and skeg stiffness on whirl speed are presented graphically in APPENDIX 4, FIG.1. The predicted whirling speeds are clearly within the ± 10% band of the design operating speed of 130 r.p.m.

If the shipbuilders own structural analysis or other tests confirms our stiffness figure, then classification will require vibration testing during trials. However, if substantial stiffening of the skeg; confirmation of a stiffness of the order of 80 tonnes/mm or alternatively a change to a 3 bladed propeller design is possible, then vibration problems up to design speed will be avoided and testing will not be required.

5. ALIGNMENT

The alignment should aim to give evenly distributed bearing loads in all conditions but particularly at full ahead. However, this aim cannot be met satisfactorily for all three possible driving configurations,

i) because of the different vertical gear loads (APPENDIX 3, TABLE 2) and

ii) because of the high shaft stiffness associated with the closely pitched plummer bearings adjacent to the flywheel.

Continued/...

Consideration was given to removing the after plummer and shifting the intermediate plummer aft by 2.0 m (4 frames); while there were no detrimental effects on the lateral vibration and whirling characteristics of the shafting, the improvements in shafting flexibility were only marginal and did not warrant the modifications necessary. The bearing load influence coefficients for the shafting arrangement as submitted are thus given in APPENDIX 5, TABLE 1. X9

An alignment has been chosen therefore that gives satisfactory load distributions

a) when both engines are driving and

b) when the outboard engine alone is driving.

For the configuration when the inboard engine alone is driving, the tangential tooth load vertically upwards on the main wheel is barely sufficient (even at full power) to move the gear shaft through the radial clearance in the aft gear bearing while conversely the forward gear bearing will be substantially loaded. The possible misalignment of the main gear wheel and driving pinion at part loads on the inboard engine is not therefore, considered satisfactory, so continuous running in this condition cannot be recommended.

An alignment procedure is given in APPENDIX 6.

The various stages of the alignment procedure showing predicted bearing and support point loads are illustrated in APPENDIX 2, STAGES 1 to 5.

The predicted bearing loads when running in the three possible driving configurations, both hot and cold, are summarized in APPENDIX 7, TABLE 1.

Advanced Engineering Services.

NHS/CL.

PLANS USED IN THE ANALYSIS.

BURRARD YARROWS CORPORATION:

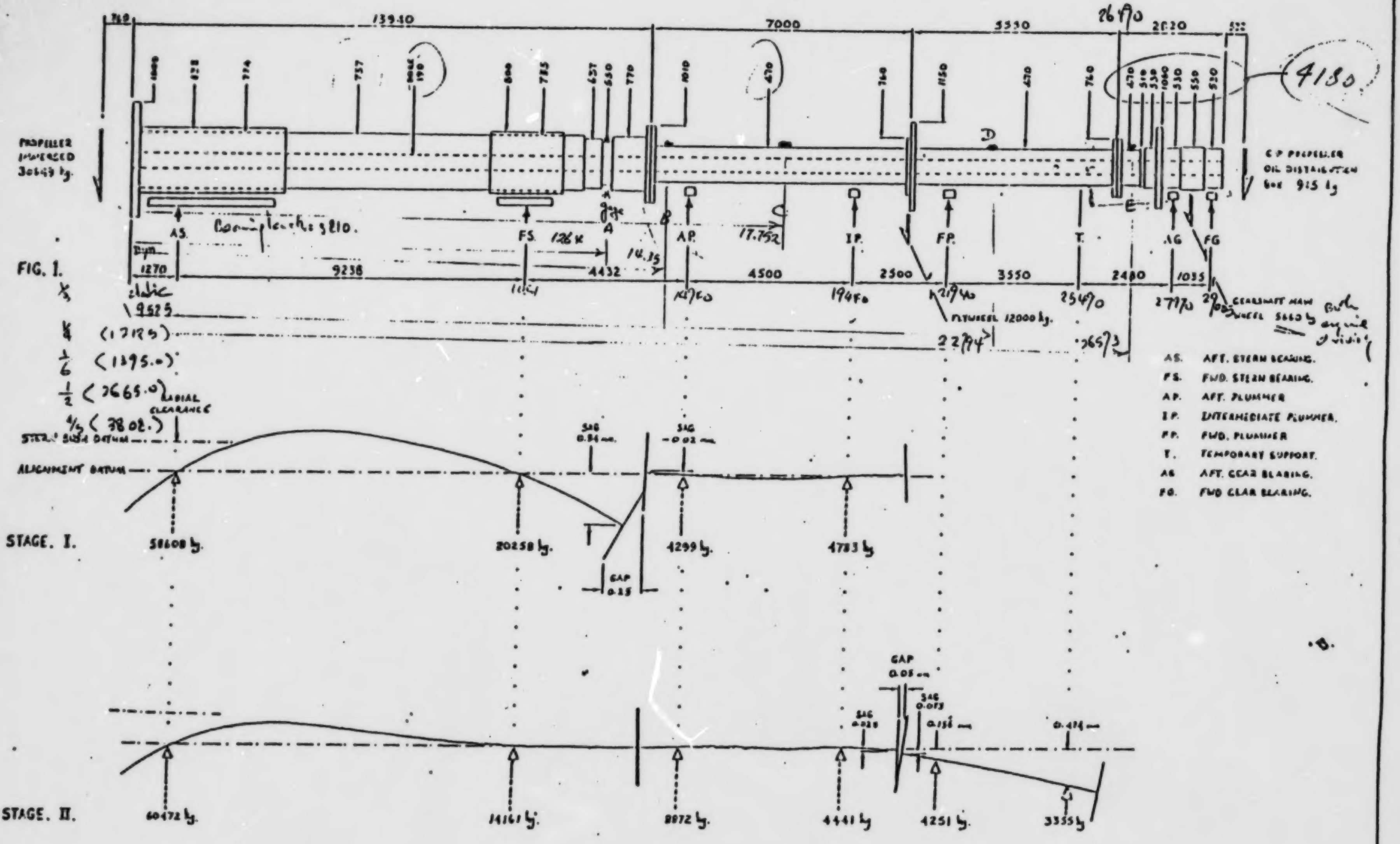
Arrangement and details of shafting	61-00-01
Skeg in way of shaft brackets	07-12-10/11 Rev.3.
Arrangement of stern tube.	61-00-02

LOHMANN & STOLTERFOHT.

Ship's twin reduction gear	2/7996/0745/1
Compensation values for alignment	12/240435/436
Gearshaft	1/0241/5019/2
Gearwheel	0/0310/5004/0
Gearbox casing	0/0137/5035/1(Sht. 1&2)
Shaft bearing	1/7973/5042/0

LIPS B.V.

Arrangement of shafting	A.006759/0100331E
Propeller shaft	A.006700/1000421
Intermediate shaft	A.006821/1600131
Intermediate shaft	A.006822/1600130
C.P. propeller	A1. 11582
Arrangement of stern tube	A.006827/0930063
Forward bearing bush	W.004500936 A.
After bearing bush	W.004500937 A.



FIGURE

LLOYD'S REGISTER OF SHIPPING

DEPT: ADVANCED ENGINEERING SERVICES.

SUBJECT BURRARD YARROWS 1-01/5-54 : PROPELLER SHAFTING ALIGNMENT.

DATE NOV '82

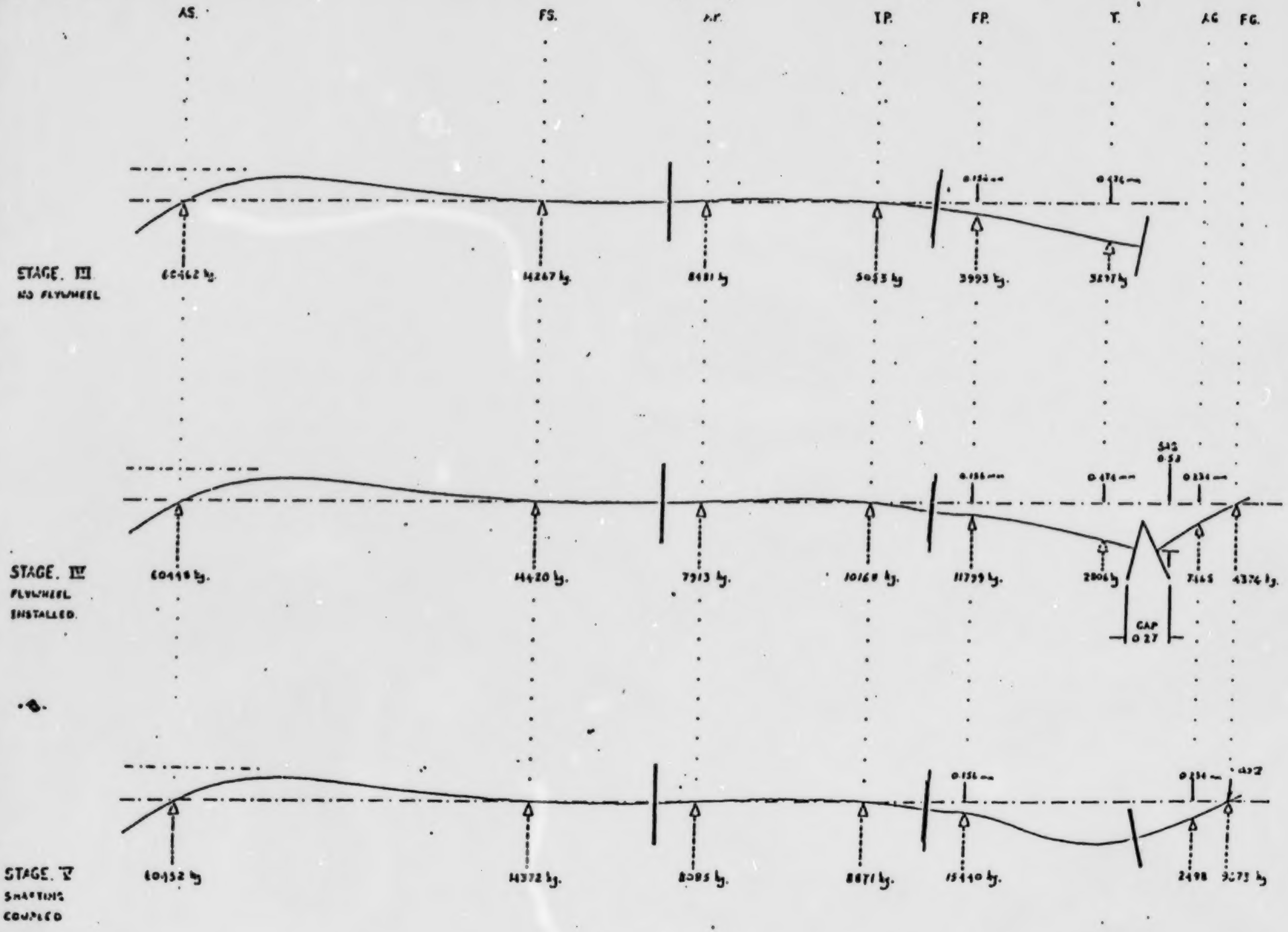


FIGURE	LLOYD'S REGISTER OF SHIPPING	DEPT: ADVANCED ENGINEERING SERVICES.	SUBJECT BURRARD YARROWS 1-07/5-54 : PROPELLER SHAFTING ALIGNMENT.	DATE [illegible]

APPENDIX 3

TABLE 1
PROPELLER DATA

DRY

Mass	35027 kg.
Polar Moment of Inertia	33028 kg. m^2
Diametral Moment of Inertia	16514 kg. m^2
Mean Pitch	4.94 m
Diameter	4.8 m
Pitch/Diameter Ratio	1.029
Blade Area Ratio	0.55
No. of Blades	4

ENTRAINED WATER (Schwaneckes' Method)

Lateral Mass	1839 kg
Polar Moment of Inertia	4680 kg. m^2
Diametral Moment of Inertia	7632 kg. m^2

BUOYANCY FORCE

Propeller Immersed	4378 kg.

APPENDIX 3

TABLE 2

MAIN GEAR WHEEL DATA

Mass	5660 kg
Helix Angle (Right Hand)	14°
Pressure Angle	20°
Polar Moment of Inertia	4023 kg. m^2
Tangential load (per engine on main wheel)	24867 kg.

VERTICAL LOADS AT MAIN GEAR WHEEL STATION (+ ve downwards)

Both engines driving	5660 kg
Outboard engine driving	30527 kg
Inboard engine driving	-19207 kg

TABLE 3

FLYWHEEL DATA

Mass	12000 kg
Polar Moment of Inertia	18154 kg m^2

		A.S.B. STIFFNESS (t/mm.)						SHAFT SUPPORT POINT IN A.S.B.
		20	30	40	50	70	100	
WHIRL SPEED R.P.M.	FWD.	–	135	149	159	173	184	$\frac{1}{6}$ LENGTH
	REV.	114	133	146	155	168	178	
WHIRL SPEED R.P.M.	FWD.	108	125	136	145	156	166	$\frac{1}{4}$ LENGTH
	REV.	107	123	134	142	152	161	
WHIRL SPEED R.P.M.	FWD.	101	116	125	133	142	150	$\frac{1}{3}$ LENGTH
	REV.	100	114	123	130	139	146	

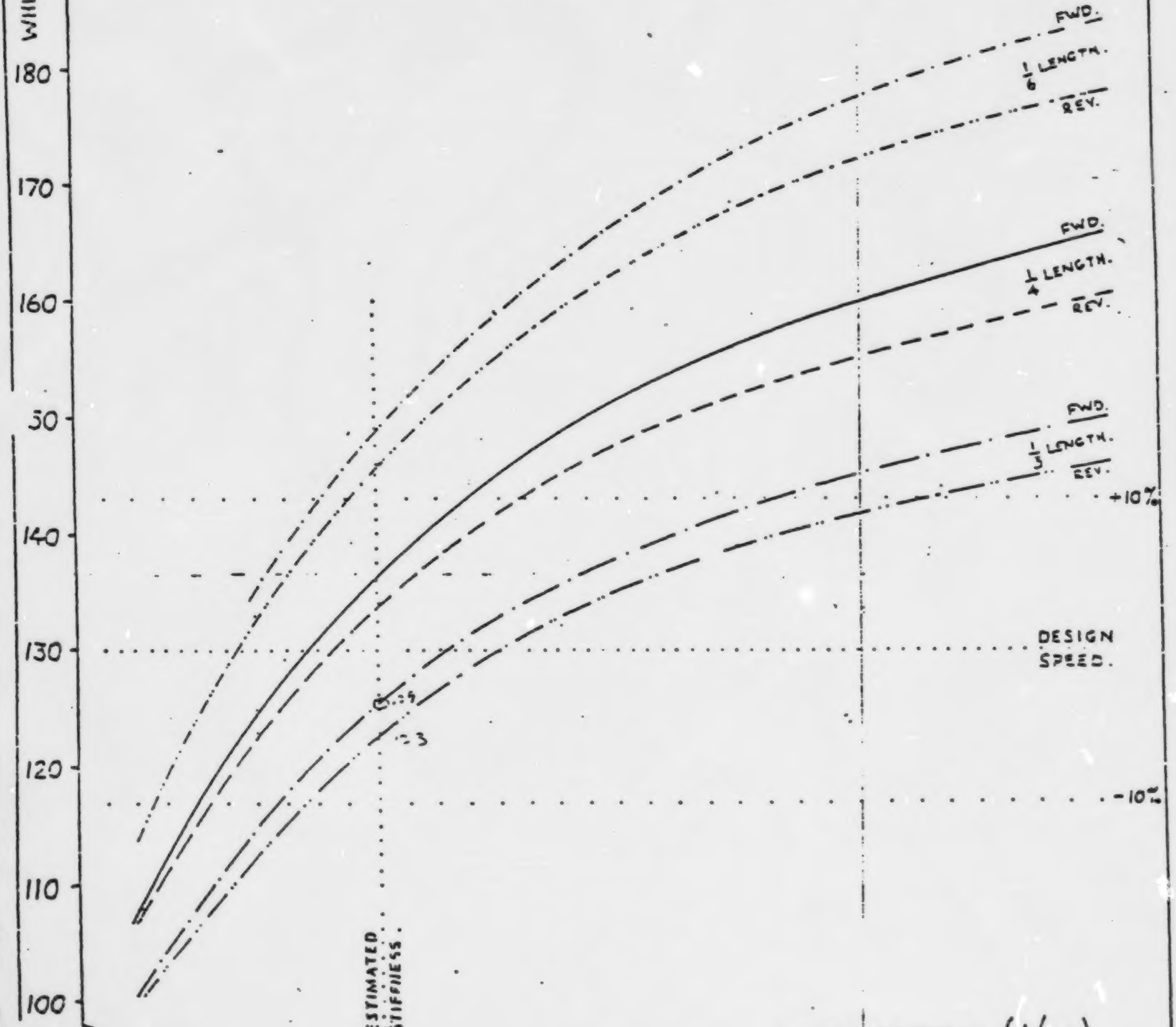


FIGURE 1.

LLOYD'S REGISTER OF SHIPPING

DEPT: A.E.S.

DATE NOV.'82

SUBJECT: BURRARD YARROWS 1.07 & 5.54 : LATERAL VIBRATION

TABLE 1.

BEARING LOADS INFLUENCE COEFFICIENTS.

(i) Table shows change in ΔR bearing load (kg) when any one bearing is lowered by 1.0mm.

(ii) Bearings are numbered from aft.

	1 (A.S.)	2 (F.S.)	3 (A.P.)	4 (I.P.)	5 (F.P.)	6 (A.G.)	7 (F.G.)
1	-807	2653	-2065	334	126 -216	32	-21
2	2653	-9942	9609	-3548	1339	-337	226
3	-2065	9609	-12913	9929	-4969	1250	-841
4	334	-3548	9929	-19144	15507	-9395	6317
5	-126	1339	-4969	+15507	-16804	18375	-13322
6	32	-337	1250	-9395	18375	-50426	40501
7	-21	226	-841	6317	-13322	40501	-32861

For a linear System

$a_{ij} = a_{ji}$

Maxwell reciprocal relation should apply.

APPENDIX 6

ALIGNMENT PROCEDURE

NOTES:

a) Until the alignment procedure states otherwise, the flywheel should be safely supported and chocked, just aft of its installation position so as no to load the shafting.

b) As the shafting will lie in the bottom of the bearings during alignment, then the alignment datum (to which all the following measurements are referred) will be below the stern bush datum by an amount equal to the radial clearance in the stern bearings.

c) The alignment is described such that it may be effected either optically or with reference to flange gaps and sags.

---

i) With the vessel in dock, the after and forward stern bushes are bored parallel and concentric on the stern bush datum.

ii) The after plummer and intermediate plummer are set on the alignment datum; the forward plummer is set to bring the shaft centreline 0.156 mm below the alignment datum at the plummer position and a temporary support (arranged 1.0 m aft of the forward intershaft forward flange face) should be set to bring the shaft centreline 0.474 mm below the alignment datum.

iii) With the vessel afloat, the tailshaft installed, propeller fitted and the after intershaft supported on the after and intermediate plummers, a bottom gap between the flanges of 0.25 mm should be measured with the intershaft flange being 0.86 mm higher than the tailshaft flange. The

Continued/

tailshaft flange may be jacked up (load 5570 kg) until concentric with the intershaft flange, the bolts installed and the two shafts coupled.

iv) With the forward intershaft supported by the forward plummer (0.156 mm below datum) and the temporary support (0.474 mm below datum), a top gap of 0.05 mm should be measured between the Ø 760 mm aft intershaft, forward flange, and the Ø 1150 mm forward intershaft, aft flange. In addition, the Ø 760 mm flange centre should be 0.05 mm above the Ø 1150 mm flange centre.

The aft intershaft and forward intershaft may now be coupled together.

v) Maintaining the temporary support position, the flywheel may now be installed. The load on the temporary support should be seen to change from 3297 kg without flywheel to 2806 kg with flywheel installed.

vi) The gearbox may now be set such that the output shaft flange is concentric with the forward intershaft forward flange but with a bottom gap of 0.27 mm.

This will set the forward and aft gear bearings at their prescribed alignment heights referred to datum- so the gearbox may now be chocked, the gearbox output flange coupled to the intershaft flange and the temporary support removed.

APPENDIX 7

TABLE 1

PREDICTED BEARING LOADS IN EACH RUNNING CONFIGURATION.

		BEARING LOAD (Kg)						
		1 (A.S.)	2 (F.S.)	3 (A.P.)	4 (I.P.)	5 (F.P.)	6 (A.G.)	7 (F.G.)
Both Engines Driving	Hot	60450	14339	7989	9591	14257	4821	7885
	Cold	60452	14373	8085	8871	15440	2498	9673
Outboard Engine Driving	Hot	60450	14403	7975	9699	14029	15728	21976
	Cold	60452	14337	8071	8979	15211	13405	23764
Inboard Engine Driving	Hot	60445	14454	7787	11114	11808	-826	-10255
	Cold	60447	14428	7883	10393	12990	-3148	-8468

BEARING DISPLACEMENTS FROM DATUM (mm)

(+ ve downwards)

Chosen Alignment	Hot	0.0	0.0	0.0	0.0	0.156	0.0	-0.23
	Cold	0.0	0.0	0.0	0.0	0.156	0.234	0.00

```
STATIC BEARING REACTIONS ON M.V. KALVIK
FILE NAME STAT_22

POSITION                 BENDING MOMENT                SHEAR
                             [MNm]                      [MN]

SB36                          .014                     -.008
SB39                         -.044                     -.062
SB46                         -.015                      .009
SB56                          .002                      .026
SB63                          .030                     -.007


BEARING                 VERTICAL REACTION         TRANSVERSE REACTION
                              [MN]                       [MN]

AFT STERN TUBE                .628                     0.000
FWD. STERN TUBE               .117                     -.003
1st. INT.                     .109                      .001
2nd. INT.                     .067                     -.002
3rd. INT.                     .124                      .013
AFT GEAR                      .040                     -.033
FWD. GEAR                     .068                      .024

SUM OF REACTIONS (MN)=      1.153                      0.000

SUM OF SHAFT WEIGHTS (MN)   1.153


ALIGNMENT DATE   : 15 SEP 1986
CALCULATION DATE: 10 Feb 1987


CALCULATED OFFFSETS

     BEARING              mm

AFT STERN TUBE         20863.7
FWD. STERN TUBE        13975.1
1st. INT.              10664.0
2nd. INT.               7277.9
3rd. INT.               5383.7
AFT GEAR                 790.0
FWD. GEAR                 -0.0
```

```
STATIC BEARING REACTIONS ON M.V. KALVIK
FILE NAME

POSITION                  BENDING MOMENT            SHEAR
                              [MNm]                  [MN]

                                                     -.009
SB36                           .015                  -.064
SB39                          -.045                   .009
SB46                          -.014                   .027
SB56                           .002                  -.007
SB63                           .031


BEARING                 VERTICAL REACTION      TRANSVERSE REACTION
                              [MN]                   [MN]

                                                     -.001
AFT STERN TUBE                 .628                   .003
FWD. STERN TUBE                .115                  -.005
1st. INT.                      .111                   .001
2nd. INT.                      .066                   .010
3rd. INT.                      .125                  -.031
AFT GEAR                       .039                   .023
FWD. GEAR                      .069

SUM OF REACTIONS (MN)=        1.153                  0.000

SUM OF SHAFT WEIGHTS (MN)     1.153


ALIGNMENT DATE   :  4 Aug 1986
CALCULATION DATE: 10 Feb 1987


CALCULATED OFFFSETS

     BEARING                mm

AFT STERN TUBE            20866.1
FWD. STERN TUBE           13976.6
1st. INT.                 10665.2
2nd. INT.                  7278.6
3rd. INT.                  5384.2
AFT GEAR                    790.1
FWD. GEAR                    -0.0
```

APPENDIX D

Field Notes and Calibration Calculations

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT M.V. KALVIK PROPULSION SYSTEM
SUBJECT CALIBRATION, LOCATION, IDENTIFICATION AND OFFSET TABLE

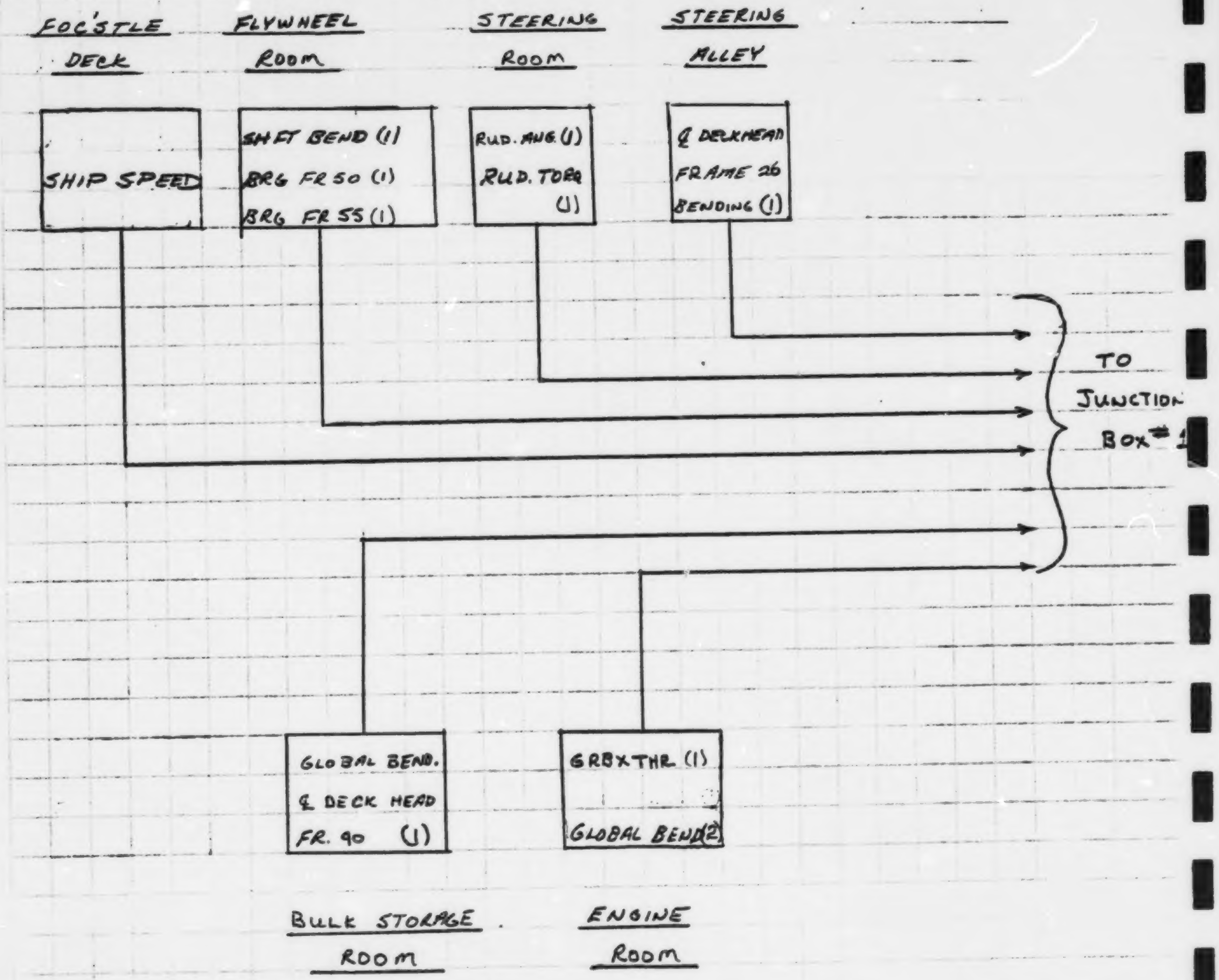
SHEET 1 OF 1
DATE FEB 18/85
BY
CH'K. BY

CHANNEL ID	DESCRIPTION / LOCATION	[illegible]	[illegible]
EFR	ENGINE FUEL RACK #3 MAIN ENGINE	66.9 mm/VOLT	2.2 mm
PITCH	STARBOARD PROPELLER PITCH	-26.5 Deg/Volt AHEAD	-0.19 Deg
		-17.0 Deg/Volt ASTERN	0.50 Deg
RDA	RUDDER ANGLE	31.8 Deg/VOLT	67.7 Deg
RTQ	RUDDER TORQUE	3.822 KNm/µE	0
GBA	GEAR BOX THRUST AFT	99.5 µE/Volt	0
GBF	GEAR BOX THRUST FWD.	99.5 µE/Volt	0
DB 26	DECK BENDING AT FRAME 26 ℄	99.5 µE/Volt	0
DB 43	DECK BENDING AT FRAME 43 ℄	99.5 µE/Volt	0
DB 43LS	DECK BENDING AT FRAME 43 LOWER	99.5 µE/Volt	0
DB 68	DECK BENDING AT FRAME 68 ℄	99.5 µE/Volt	0
BR 41S	INTER. BEARING AT FRAME 41 STBD	9 KN/µE	0
BR 41 P	" " " " 41 PORT	9 KN/µE	0
BR 50 S	" " " " 50 STBD	99.5 µE/Volt	0
BR 50 P	" " " " 50 PORT	99.5 µE/Volt	0
BR 55 S	" " " " 55 STBD	99.5 µE/Volt	0
BR 55 P	" " " " 55 PORT	99.5 µE/Volt.	0
THRUST	STARBOARD PROPSHAFT THRUST	26.9 µE/Volt	0
ATQ	ASEA TORDUCTOR STBD.	766 KN.m/Volt	0
SB 36	SHAFT BENDING FRAME 36		0
SB 39	SHAFT BENDING FRAME 39	110 µE/Volt	0
SB 46	SHAFT BENDING FRAME 46	200 µE/Volt.	0
ACV 34 P	PORT SIDE ACCELEROMETER AFT	10.64 m/s^2/Volt	0
ACV F	FORWARD ACCELEROMETER	10.55 m/s^2/Volt	0
ACV 34S	STBD. SIDE ACCELEROMETER AFT	8.5 m/s^2/Volt	0
SPEED	DOPPLER SPEED LOG FOC'STLE DECK	29.3 mph/Volt	0
PROX F1	FORWARD END OF STERNTUBE	50 mv/mil	0
PROX F2	FORWARD END OF STERNTUBE	50 mv/mil	0
ANG POS	ANGULAR POSITION AND RPM	1 pulse/Rev	0

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO.
PROJECT
SUBJECT PROPULSION SYSTEM GENERAL WIRING CONFIGURATION

SHEET 1 OF 2
DATE AUG 3/86
BY AL
CH'K. BY



NOTE: ALL CABLES FROM ABOVE SIGNALS ARE BELDEN 4 CONDUCTOR

ARCTEC CANADA LIMITED

ENGINEERING DESIGN CALCULATIONS

SHEET 2 OF 2

JOB. NO.

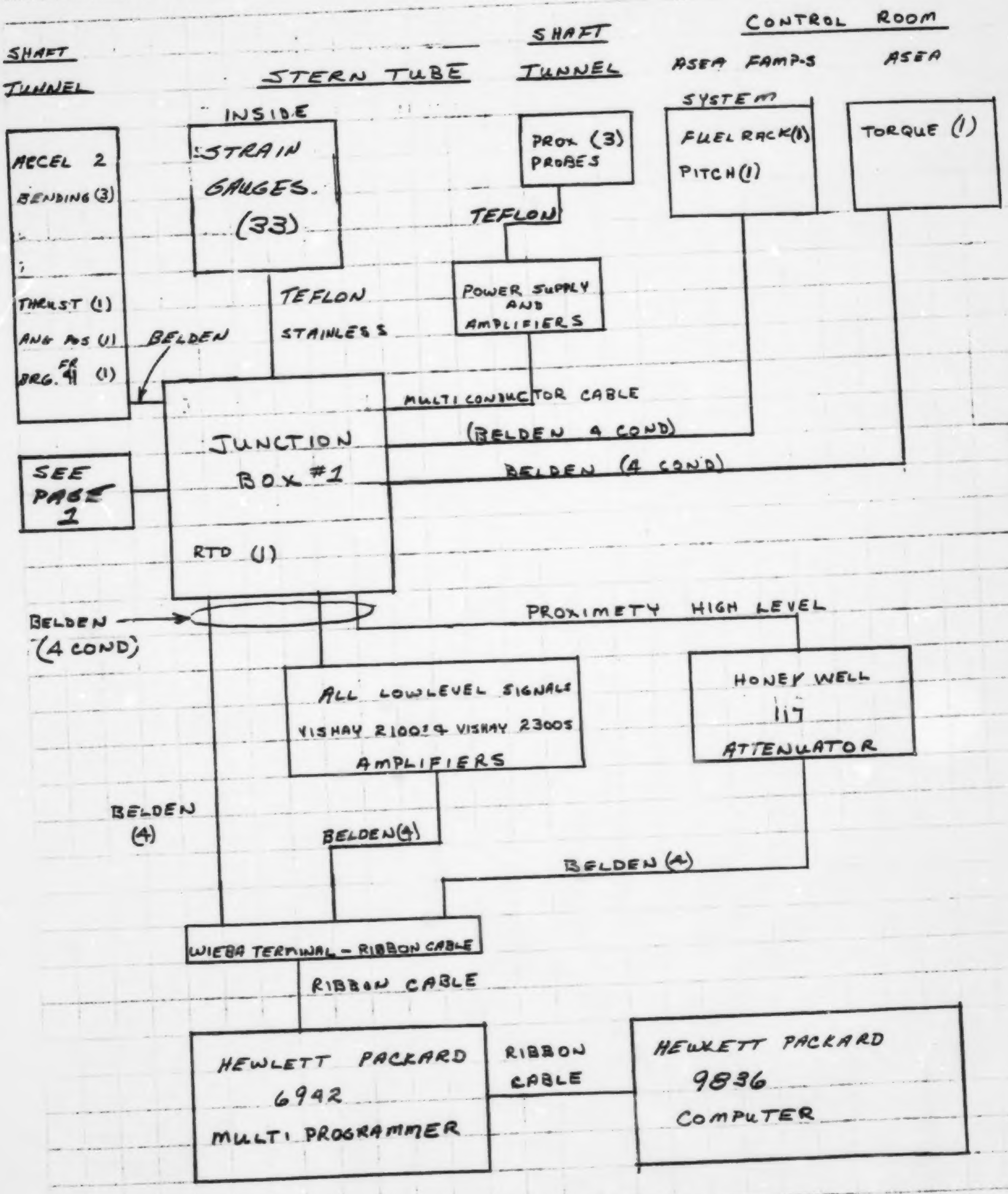
DATE AUG. 3 /86

PROJECT

BY PL

SUBJECT PROPULSION SYSTEM GENERAL WIRING CONFIGURATION

CH'K. BY



ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452C
PROJECT MV KALVIK
SUBJECT ENGINE FUEL RACK CALIB.

SHEET .... OF .....
DATE 02/18/8
BY Al
CH'K. BY ....

CHANNEL ID	CALIBRATION	OFFSE
FUEL RACK #3	66.9 mm/Volt	2.2 m

NOTE: FOR THE PROPULSION STUDY THE ENGINE FUEL RACK #3 WAS MONITORED FROM THE SHIP'S CONTROL ROOM SIGNAL.

ARCTEC CANADA LIMITED

ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT M.V KALVIK
SUBJECT FUEL RACK CALIBRATION
BEFORE ADJUSTMENT OF ASEA POT

SHEET .... OF .....
DATE 86/09/10
BY DNBC/M.
CH'K. BY ....

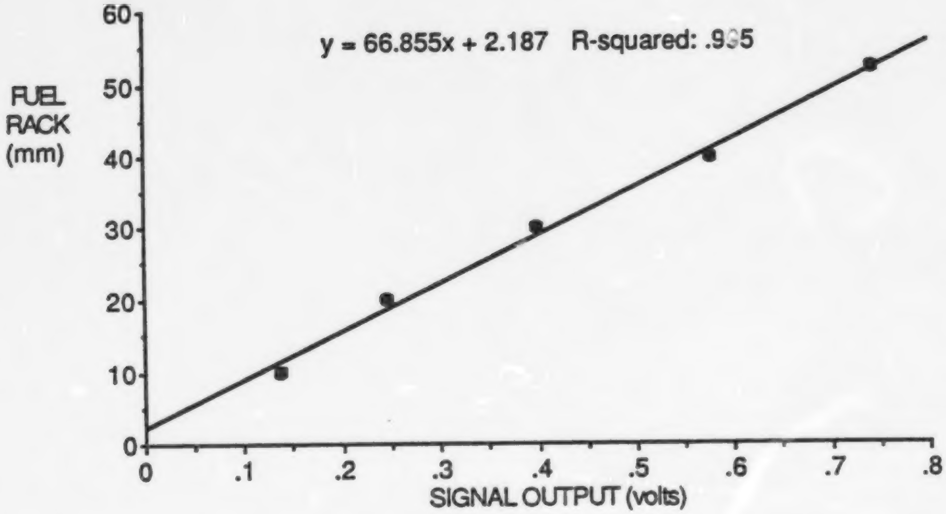
M.E. #3

VOLTAGE VOLTS	RACK SETTING (mm)
0.745	52
0.580	40
0.400	30
0.247	20
0.138	10
0.095	– ①
-0.020	0

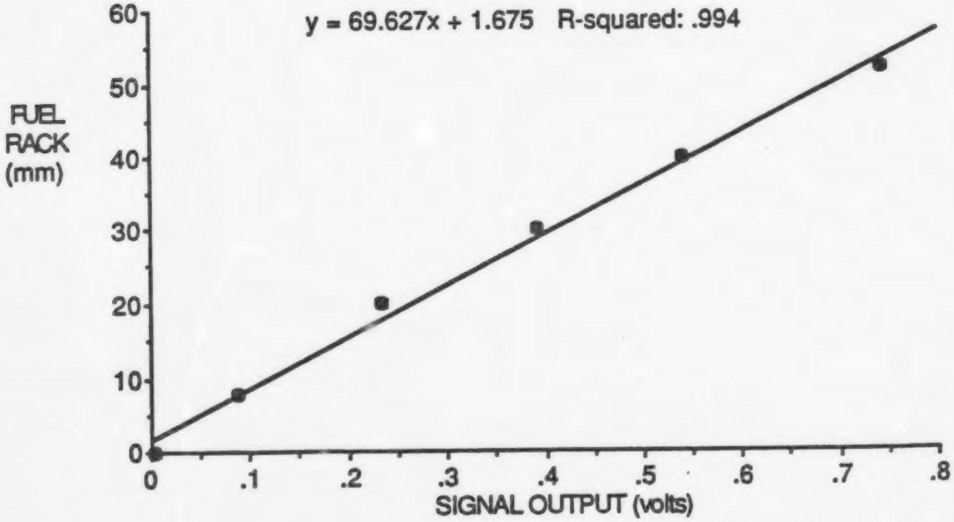
M.E #4

VOLTAGE VOLTS	RACK SETTING (mm)
0.745	52
0.542	40
0.393	30
0.235	20
0.070	8
-0.005	–
0.090	–

CALIBRATION OF FUEL RACK NUMBER 3



CALIBRATION OF FUEL RACK NUMBER 4



ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

SHEET 1 OF
DATE FEB 18/8
BY
CH'K. BY

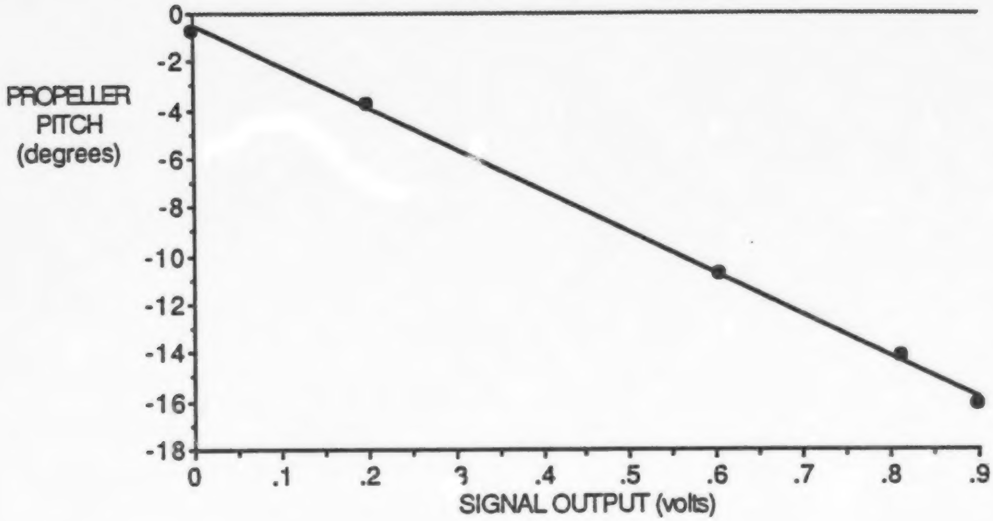
JOB. NO. 2452C
PROJECT M.V. KALVIK PROPULSION
SUBJECT PROPELLER PITCH CALIBRATION

COMPONENT	CALIBRATION	OFFSET
STARBOARD PITCH	-26.5 Deg/Volt AHEAD	-0.19 Deg.
	-17.0 Deg/Volt ASTERN	0.50 Deg.
PORT PITCH	-25.5 Deg/Volt AHEAD	0.2 Deg
	-16.6 Deg/Volt ASTERN	-0.29 Deg

THE PROPELLER PITCH SIGNALS WERE MONITORED FROM THE SHIPS CONTROL ROOM. ONLY THE STARBOARD SIGNAL WAS USED FOR THIS STUDY.

CALIBRATION OF STARBOARD PROPELLER PITCH IN REVERSE

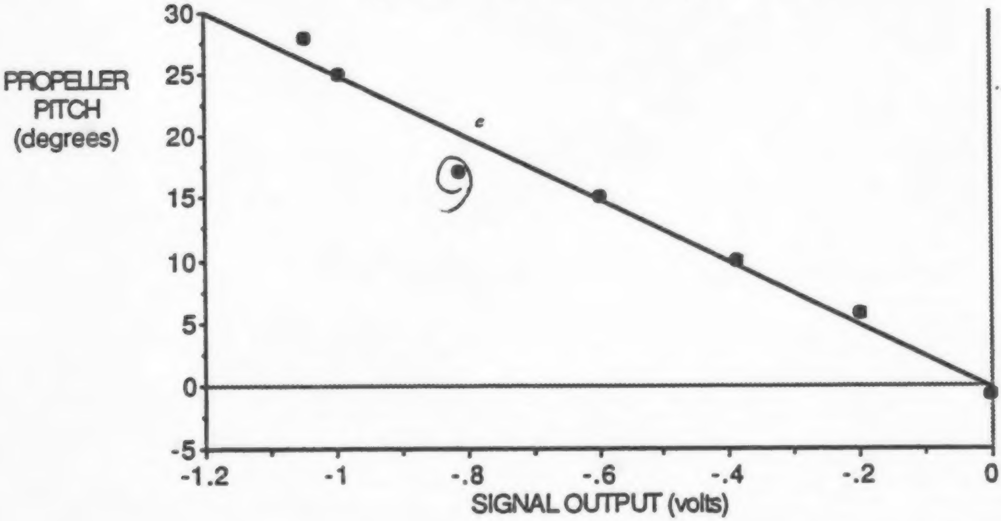
$y = -17.003x + -.501$ R-squared: .999



CALIBRATION OF STARBOARD PROPELLER PITCH AHEAD

-26.526 + -.19

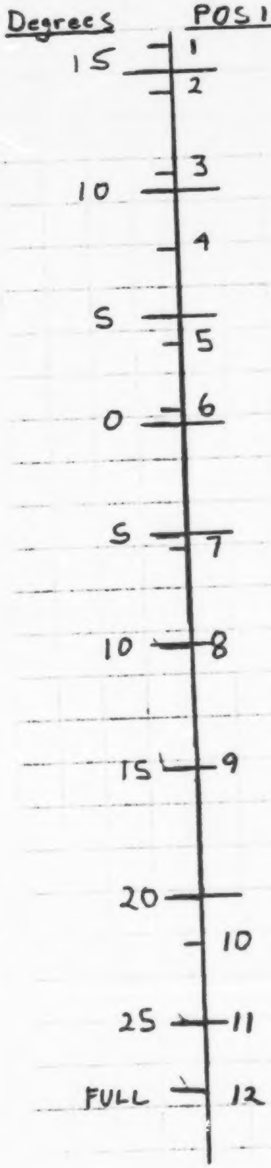
$y = -25.262x + -.233$ R-squared: .978



ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

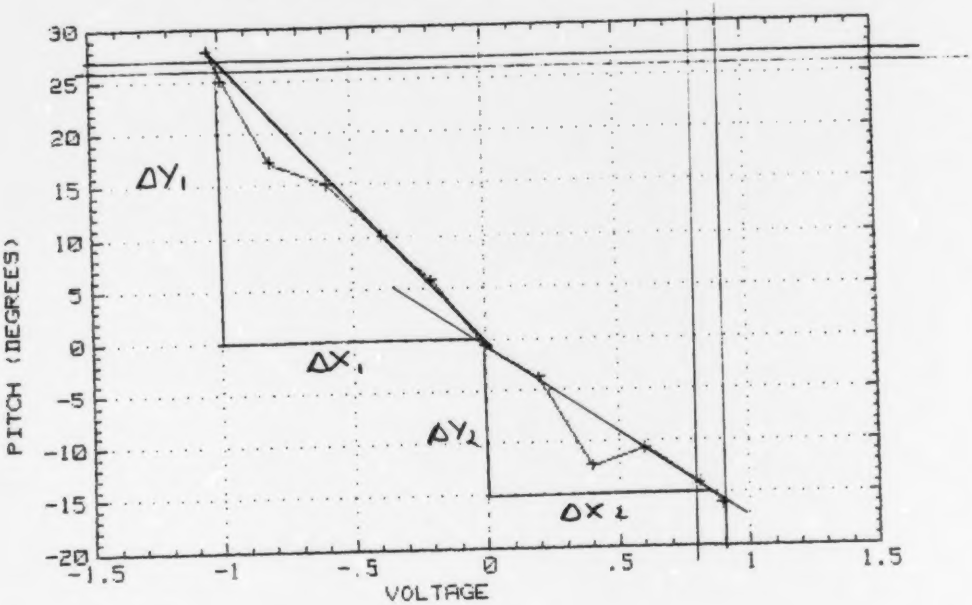
JOB. NO. 2A52
PROJECT M.V. KAVIK.
SUBJECT PROPELLER PITCH CALIBRATION

SHEET ..... OF .....
DATE 86/09/08
BY DNBC/MHF
CH'K. BY



	DEGREES	VOLTAGE	CONTROL ROOM GAUGE POS.
	-16.1	0.90	9
	-14.1	0.813	8
ASTERN	-10.7	0.605	6
	-12.3	0.40	4
	-3.75	0.20	2
	-0.67	0.00	0
	5.67	-0.198	2
	10.0	-0.383	4
AHEAD	15.0	-0.543	6
	17.2	-0.810	8
	25.0	-0.993	10
	27.9	-1.095	FULL

STBD. PITCH CALIBRATION - M.V.KALVIK



$$\frac{\Delta Y_1}{\Delta X_1} = \frac{26.5}{-1} = -26.5$$

$$\frac{\Delta Y_2}{\Delta X_2} = \frac{-15}{0.85} = -17.6$$

$Y_1 = m_1 x + b_1 = (-26.5)(x)$ AHEAD

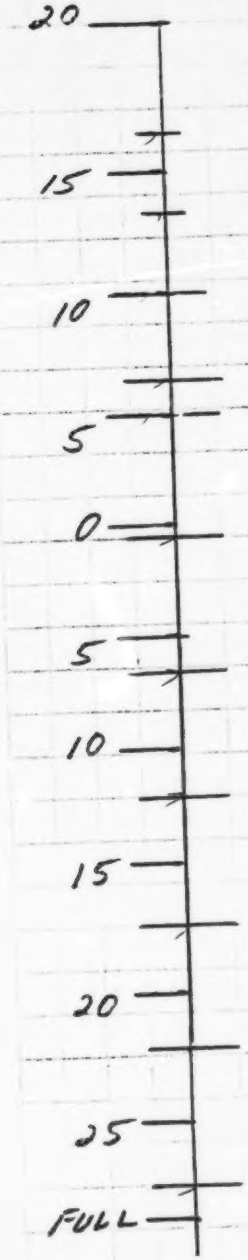
$Y_2 = m_2 x + b_2 = (-17.6)(x)$ ASTERN

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT M.V. KALVIK
SUBJECT PORT PITCH CALIBRATION

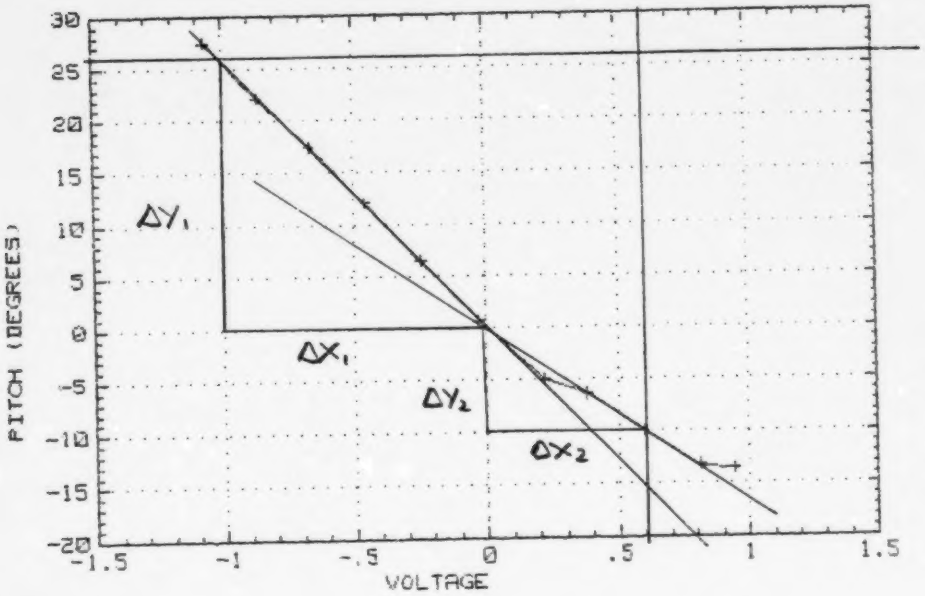
SHEET .... OF ....
DATE 86/09/10
BY DMAL
CH'K. BY

DEGRESS POSITION



POSITION		DEGREES	VOLTAGE	CONTROL ROD GAUGE POS
1	ASTERN	-16.4	0.948	9
2		-13.3	0.815	8
3		-10.0	0.60	6
4		-6.4	0.383	4
5		-5.0	0.220	2 0
6		0.63	-0.025	
7		6.4	-0.242	2
8	AHEAD	12.0	-0.453	4
9		17.4	-0.665	6
10		22.1	-0.865	8
11		27.4	-1.070	10

PORT PITCH CALIBRATION - M.V.KALVIK



$\frac{\Delta Y_1}{\Delta X_1} = \frac{-25.5}{+1.0} = -25.5$ $b_1 = 0$

$\frac{\Delta Y_2}{\Delta X_2} = \frac{-10}{0.6} = -16.7$ $b_2 = 0$

$Y = mx + b = (-25.5)(x)$ AHEAD
$Y = mx + b = (-16.7)(x)$ ASTERN
} PORT PITCH

JOB. NO. 2452C
PROJECT MV KALVIK PROPULSION
SUBJECT RUDDER CALIBRATIONS

SHEET ... OF ...
DATE FEB 18/8
BY
CH'K. BY

COMPONENT	CALIBRATION	OFFSET
RUDDER ANGLE	31.8 Deg/Volt	67.7 Deg
RUDDER STOCK TORQUE	3.822 KN.m/μE	0
DUMP PRESSURE	1260 psi = 1,187 KN·m	

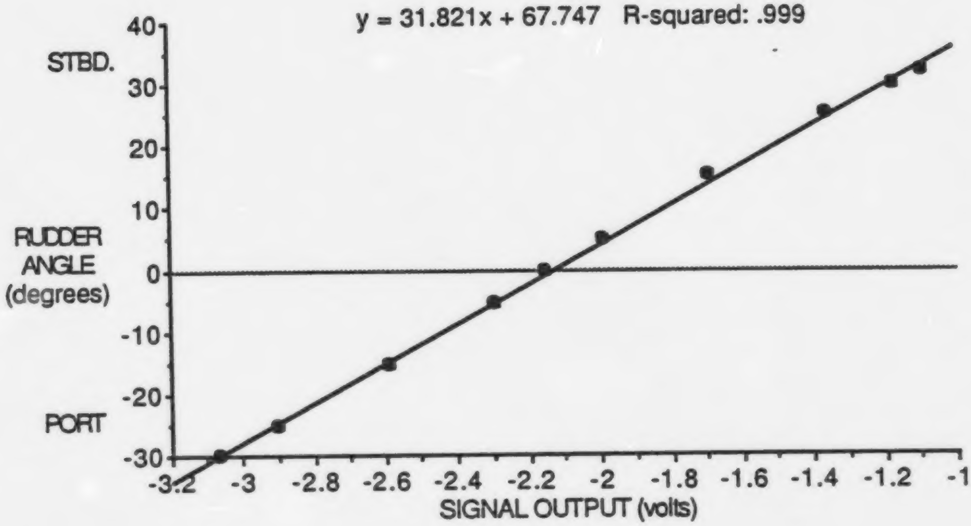
THE RUDDER ANGLE IS A SHIP CONTROL ROOM SIGNAL.
THE RUDDER STOCK TORQUE IS A FULL STRAIN GAUGE BRIDGE WITH A CALCULATED CALIBRATION FACTOR AS OUTLINED IN THIS SECTION

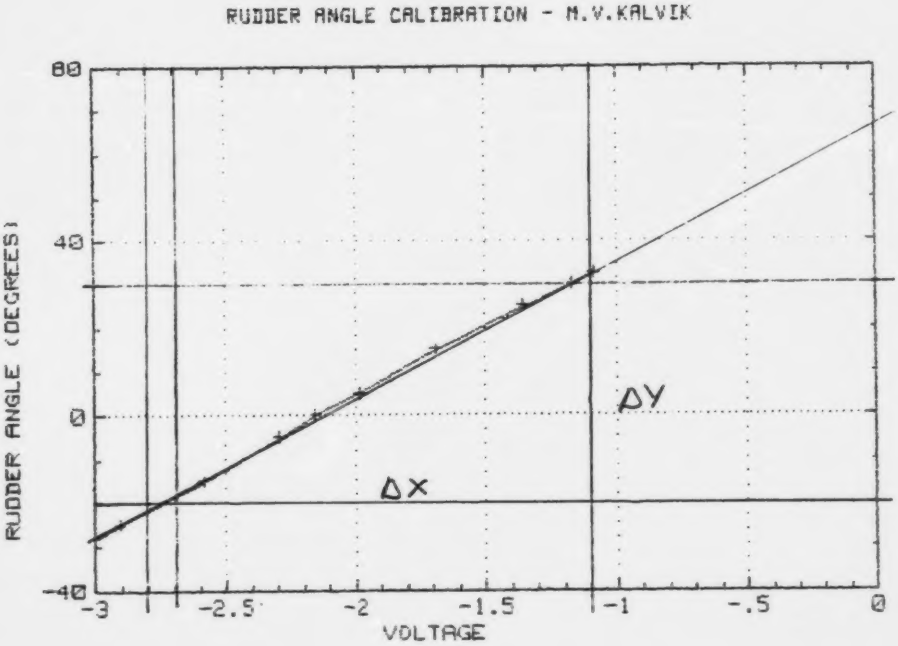
ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT
SUBJECT MACHINERY CALIBRATIONS
SHEET ... OF ...
DATE 86/09/06
BY DWBL/m
CH'K. BY

RUDDER ANGLE	VOLTAGE
0°	-2.143
- 5° PORT	-2.293
-15° P	-2.585
-25° P	-2.903
-30° P	-3.063
0	-2.152
5° S	-1.985
15° S	-1.685
25° S	-1.353
30° S	-1.165
32.5° S	-1.085

CALIBRATION OF RUDDER ANGLE





$\frac{\Delta Y}{\Delta X} = \frac{52}{1.65} = 31.5$ Deg./VOLT

b = 67 Deg

$Y = mx + b = (31.5)(x) + 67$

CALIB = (31.5)(0.005) = 0.1575

OFFS = (-67)/0.1575 = -425

ENG. UNITS = CALIB (AD COUNT - OFFS)

ARCTEC CANADA LIMITED

ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452

PROJECT

SUBJECT RUDDER TORQUE CALIBRATION

SHEET 1 OF 2

DATE 86/09/0

BY DNBC

CH'K. BY

$$V_{out} = (N/4)\, A\, V_E\, K\, \varepsilon$$

$$\varepsilon / V_{out} = 4 / [(4)(500)(10)(2.01)] = 99.5 \times 10^{-6}$$

$$\varepsilon / ADCOUNT = (99.5 \times 10^{-6})(0.005) = 0.4975 \times 10^{-6}$$

$$Q = \int_0^R (2\pi r)\, r\, dr\, \tau(r)$$

$$\tau(r) = (\tau_0)(r/R)$$

$$Q = \int_0^R 2\pi\, (r^3/R)\, \tau_0\, dr = \tau_0 \pi R^3 / 2$$

$$\tau(0) = G\gamma_0 = (E/2(1+\nu))(2)\, \varepsilon_0 \qquad \varepsilon_0 : \gamma_0/2$$

$$\tau(0) = (E/1+\nu)\, \varepsilon_0$$

$$Q = (E/1+\nu)(\pi R^3/2)\, \varepsilon_0$$

$$E = 202 \times 10^9 \text{ N/m}^2 \qquad \nu = 0.3$$

$$R = 0.50038/2 = 0.25019 \text{ m}$$

$$Q = [(202 \times 10^9)/(1+0.3)][(\pi)(0.25019)^3/2]\, \varepsilon_0$$

$$Q = 3.822 \times 10^9\, \varepsilon = (3.822 \times 10^3)(\mu\varepsilon)$$

$$\boxed{Q = 3.822 \text{ KN}\cdot\text{m}/\mu\varepsilon} \longleftarrow$$

CALIB = (3.822)(.4975) = 1.900 KN·m/AD

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT
SUBJECT RUDDER TORQUE CALIB

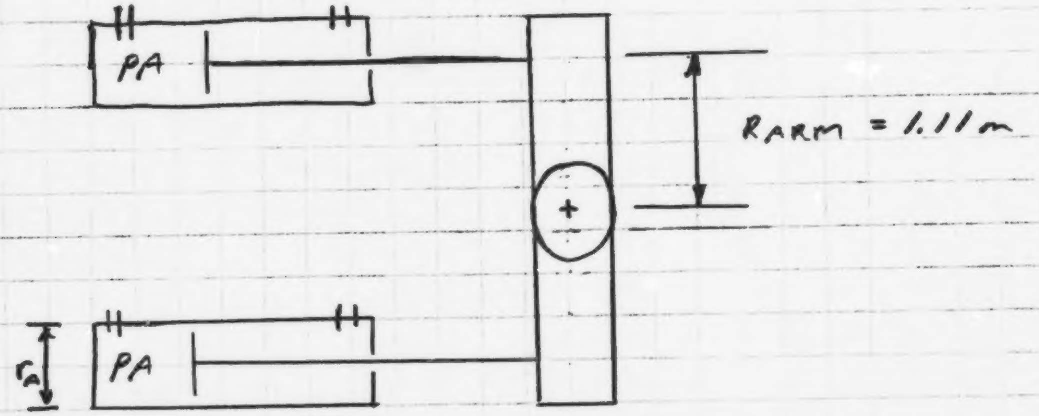
SHEET 2 OF 2
DATE 86/09/0
BY DNBL
CH'K. BY

$Q = 3.822\ \mathrm{kN \cdot m / \mu\varepsilon}$

MAX. TORQUE = 87 TON·m = 870 kN·m

$\therefore$ MAX $\mu\varepsilon$ = 870 / 3.822 = 228 $\mu\varepsilon$

DUMP PRESSURE = 1260 PSI = 8.68 MPa



$Q = 2\,P\,A\,R_{ARM}$ $P = 8.68\ \mathrm{MPa}$ $R_{ARM} = 1.11\,\mathrm{m}$

$A = (\pi)(r_A)^2 = (\pi)(.14\,\mathrm{m})^2 = 0.0616\ \mathrm{m}^2$

$Q = (2)(8.68 \times 10^6)(0.0616)(1.11) = 1.187\ \mathrm{MN \cdot m}$

$Q = 1,187\ \mathrm{MN \cdot m} = 1,187\ \mathrm{kN \cdot m} = 118.7\ \mathrm{TON \cdot m} \longleftarrow Q_L$

STRAIN FOR DUMP PRESSURE = ε_D

$\varepsilon_D = 1,187 / 3.822 = 311\ \mu\varepsilon \longleftarrow \varepsilon_D$

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452C
PROJECT MV. KALVIK PROPULSION
SUBJECT GEARBOX CALIBRATION

SHEET ... OF ...
DATE FEB 18/81
BY Al
CH'K. BY

COMPONENT	CALIBRATION	OFFSET
FORWARD GEARBOX	99.5 μE/VOLT	0
AFT GEAR BOX	99.5 μE/VOLT	0

THESE SIGNALS ARE A STRAIN GAUGE HALF BRIDGE WITH A CALCULATED CALIBRATION FACTO USING THE EQUATION ON THE FOLLOWING PAGE. THE GAUGES ARE ON THE FORWARD AND AFT SIDES OF THE GEARBOX THRUST PAD.

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT
SUBJECT
GEAR BOX CALIB.

SHEET ... OF ...
DATE 86/11/29
BY DNBC
CH'K. BY

V_E = 10 VOLTS
N = 1 ACTIVE ARM
G = 2000 = A
GF = 2.01 = K

$\mu\varepsilon/\text{VOLT} = (4)/[(N)(V_E)(A)(K)] = (4)/[(1)(10)(2000)(2.01)$

$\mu\varepsilon/\text{VOLT} = 99.5$

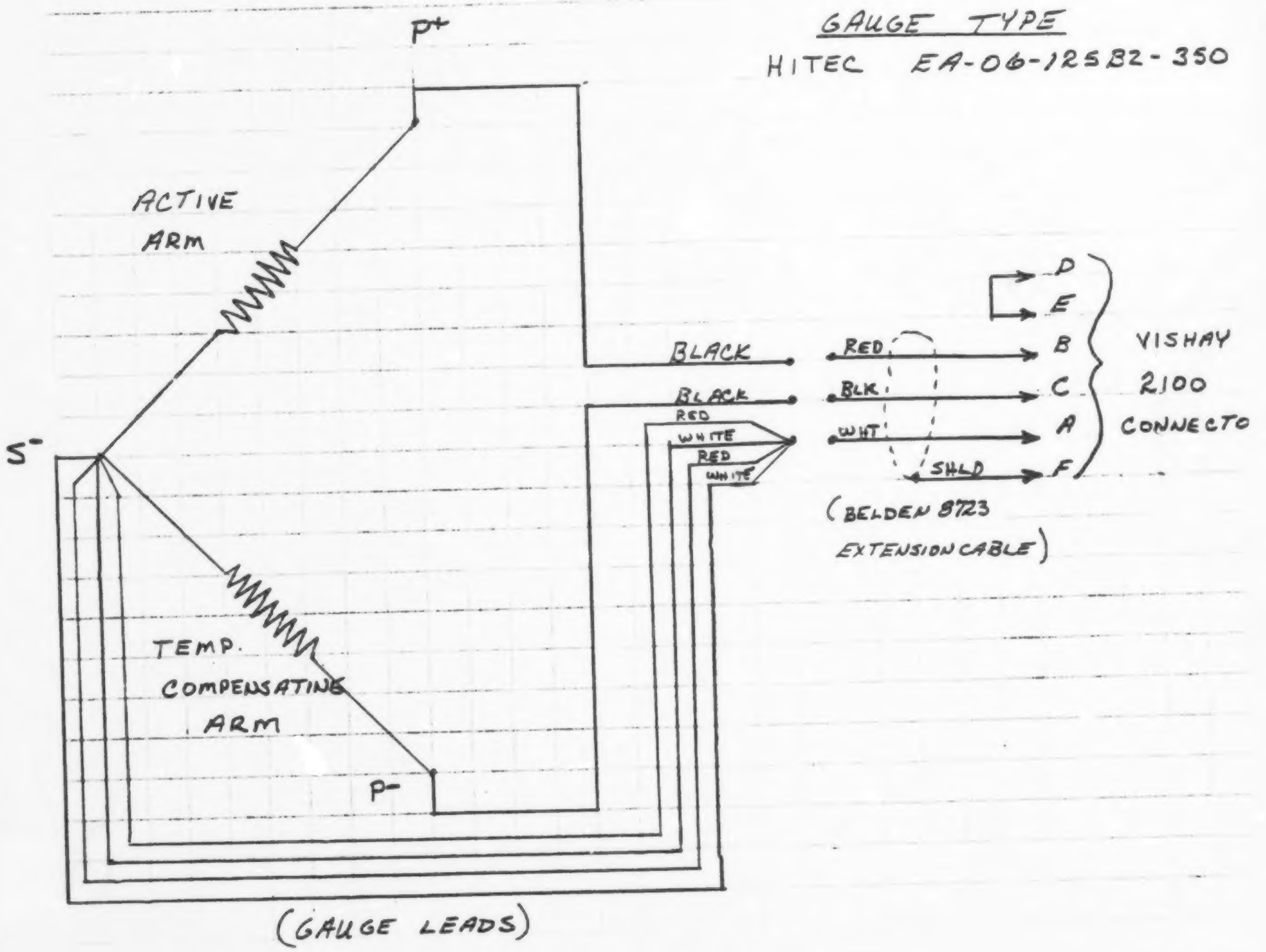
$\mu\varepsilon/\text{AD} = (99.5)(0.005) = 0.4975$

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

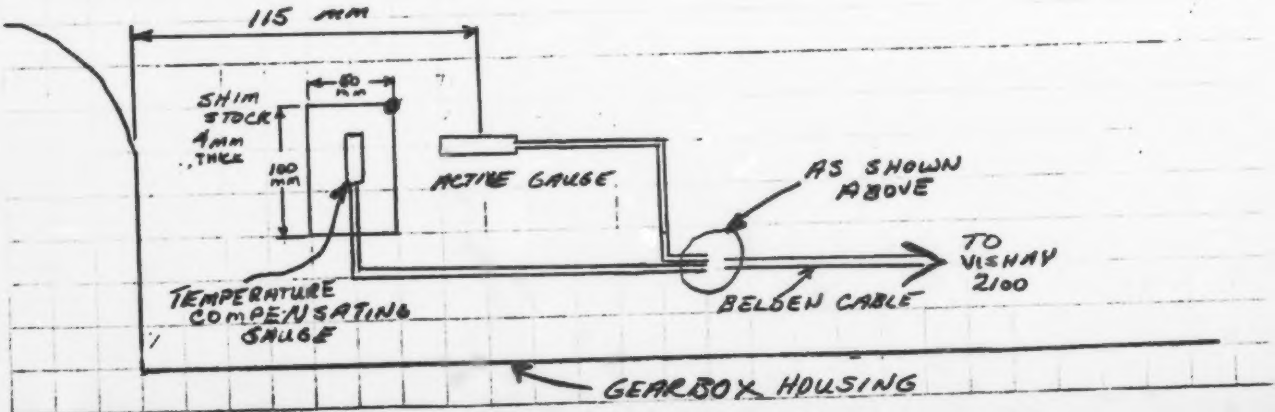
JOB. NO. 2452C
PROJECT
SUBJECT WIRING SCHEMATIC FOR GEARBOX GAUGES FORWARD AND AFT LOCATIONS

SHEET ... OF ...
DATE AUG 5, 8
BY
CH'K. BY

GAUGE TYPE
HITEC EA-06-125B2-350

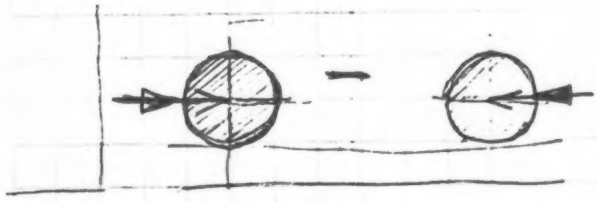


HALF BRIDGE TEMPERATURE COMPENSATING LAYOUT DIAGRAM



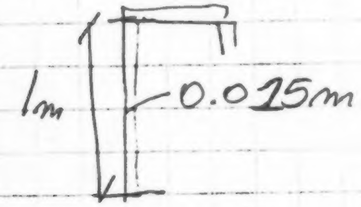
JOB. NO.
PROJECT
SUBJECT ESTIMATE OF THE STRAIN OF THE GEARBOX CASING.

SHEET 1 OF 1
DATE 7/8/86
BY VL
CH'K. BY



FORCE OF, SAY 0.3 MN (EQUAL TO R_6)

Assuming the whole strain is carried by the GEAR CASE



$A = 2 \times 1 \times 0.015 = 0.030\ m^2 + 0.30 \times 0.015 \times 2 = 0.0$

$\sigma = 0.30\ 10^6 / 0.039 = 0.7 \times 10^7\ Pa$

$\varepsilon = \dfrac{7\ 10^6}{2.1\ 10^{11}} = \underline{\underline{36.0 \times 10^{-6}}}$

actual strain will be much less.

STRAINS SETUPS RECCOMMENDED

BR 41 $20\ 10^{-6}$
BR 50, 55 $20\ 10^{-6}$
GEAR, CASE $20\ 10^{-6}$

ARCTEC CANADA LIMITED

ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452C
PROJECT MV. KALVIK PROPULSION
SUBJECT GLOBAL BENDING CALIBRATIONS

SHEET .... OF ......
DATE FEB 18/
BY Al.
CH'K. BY ....

COMPONENT	CALIBRATION	OFFSET
DB 26	99.5 μE/VOLT	0
DB 43	99.5 μE/VOLT	0
DB 43 LS	99.5 μE/VOLT	0
DB 68	99.5 μE/VOLT	0

THESE SIGNALS ARE FROM A TEMPERATURE COMPENSATED HALF BRIDGE. THE CALCULATED CALIBRATION FACTOR AND SIGNAL LOCATION ARE ON FOLLOWING PAGES IN THIS SECTION.

ARCTEC CANADA LIMITED

ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452C

PROJECT

SUBJECT WIRING SCHEMATIC FOR GLOBAL BENDING GAUGES AND BEARING LOAD GAUGES

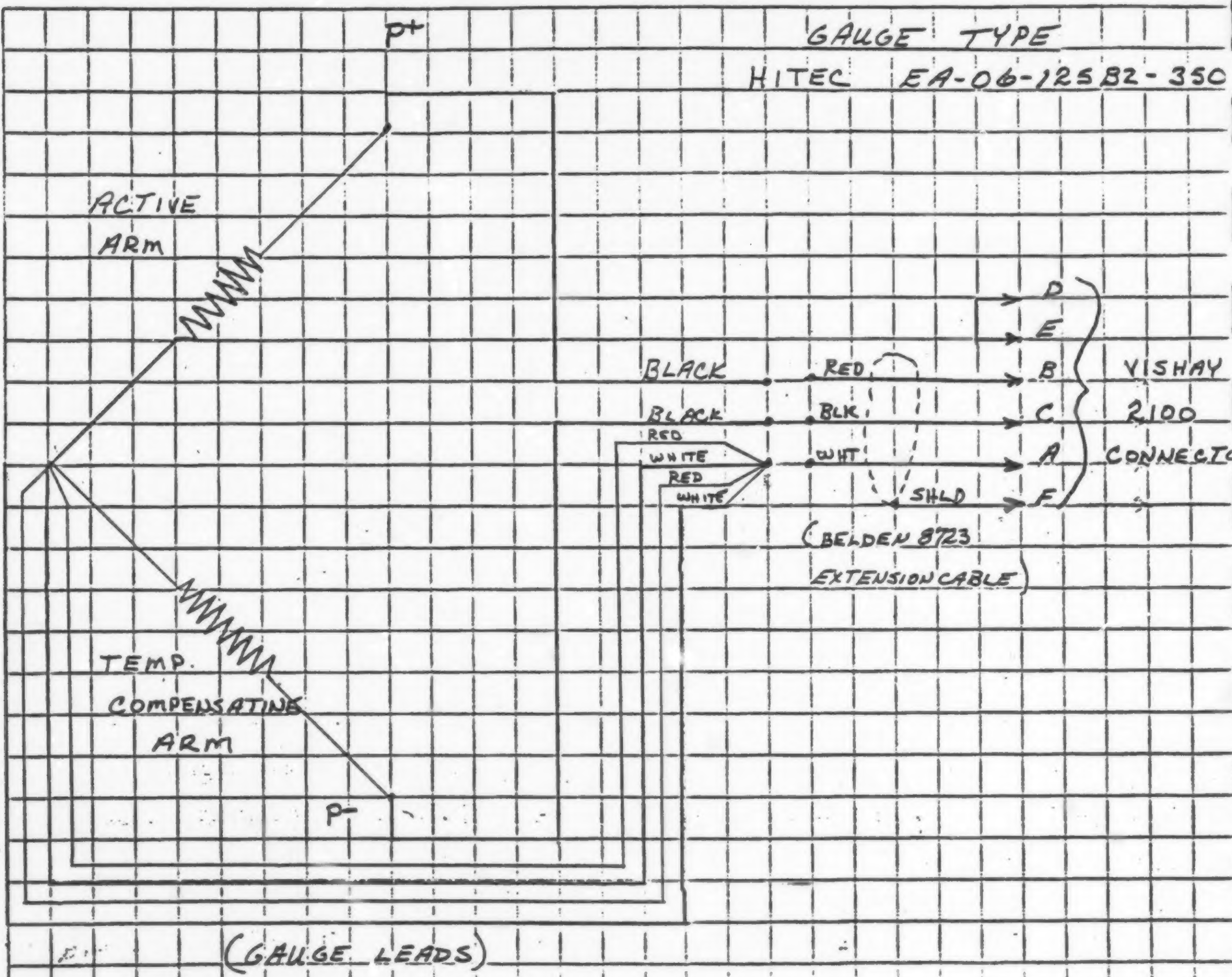
SHEET ... OF ...

DATE AUG 65,

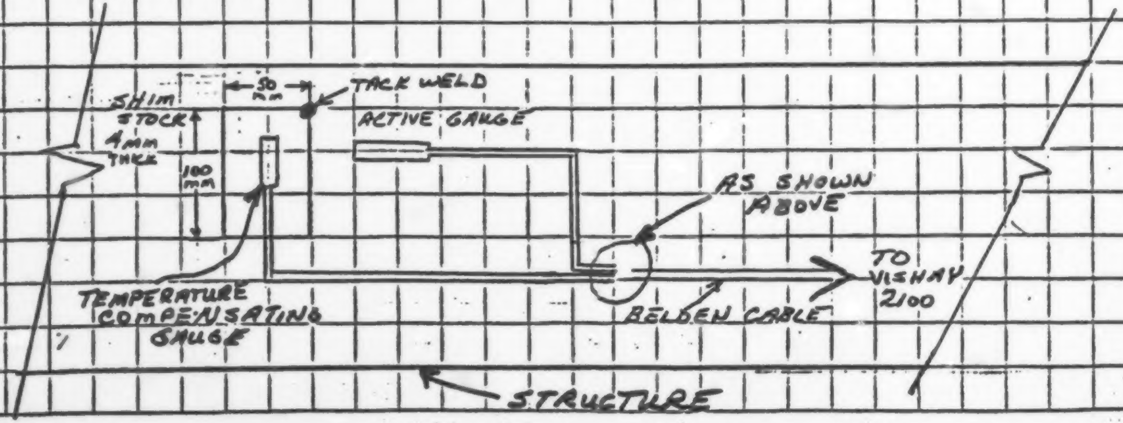
BY Al

CH'K. BY

5



HALF BRIDGE TEMPERATURE COMPENSATING LAYOUT DIAGRAM



ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT
SUBJECT
GLOBAL BENDING CALIB.

SHEET .... OF
DATE 86/11/12
BY DNBC
CH'K. BY

V_E = 10 VOLTS
N = 1 ACTIVE ARM
G = 2000 = A
GF = 2.01 = K

$\mu\varepsilon / V_{out} = [(4) / [(N)(V_E)(A)(K)] = (4) / [(1)(10)(2000)(2.01)]$

$\mu\varepsilon$ / VOLT = 99.5

$\mu\varepsilon$ / AD = (99.5)(0.005) = 0.4975

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT
SUBJECT

SHEET ...... OF ......
DATE 86/ix/11
BY RNBL/IA
CH'K. BY

LOCATION OF GLOBAL BENDING GAUGES.

DB 26 - FRAME 26 - 50 mm Below Main DK, ℄

DB 43 - FRAME 43 - 50 mm Below MDK, ℄

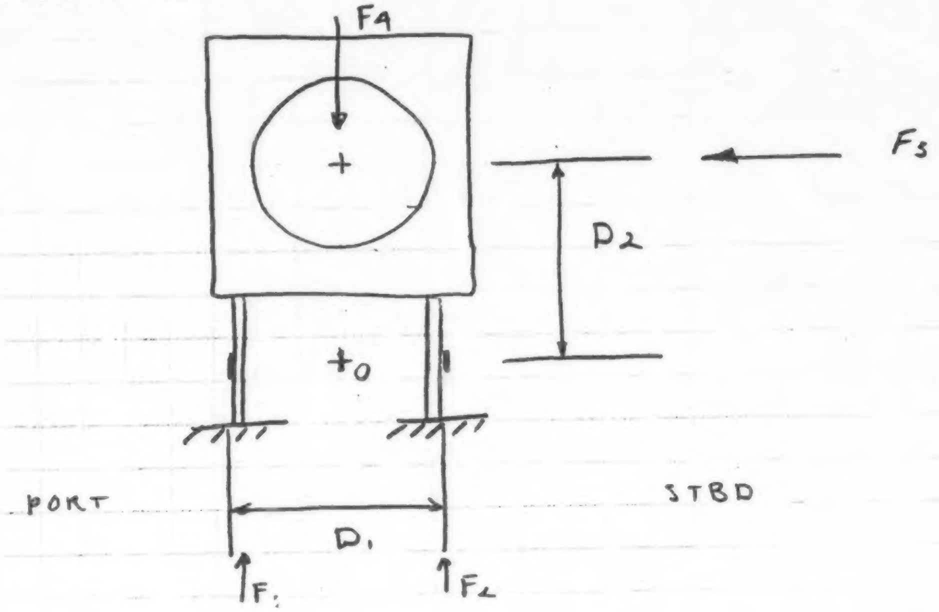
DB 43 L-S - FR 43½ - 750 mm ABOVE SHELL, 2.5 STB. of ℄

DB 68 - FR 68 - 50 mm Below MDK, ℄

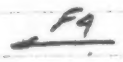
X

JOB. NO. 2452
PROJECT
SUBJECT CALCULATION OF TRANSVERSE LOAD ON SHAFT BEARINGS

SHEET 1 OF 1
DATE 87/02/25
BY DHBL
CH'K. BY



LOOKING FWD.



$\Sigma F_V = 0 \Rightarrow F_A = F_1 + F_2$

$+\circlearrowleft \Sigma M_0 = (F_3)(D_2) = (F_2)(D_1/2) - (F_1)(D_1/2)$

$$F_3 = \frac{(F_2 - F_1)(D_1/2)}{D_2} = (F_2 - F_1)\left(\frac{D_1}{2D_2}\right)$$

AFT. INTERMEDIATE BEARING : $D_1 = 0.860$ $D_2 = 0.760$
$(D_1/2D_2) = 0.57$

AFT FLY. BEARING $D_1 = 0.91$ m D_2 0.53
$(D_1/2D_2) = 0.86$

FWD FLY. BEARING $D_1 = 0.910$ m $D_2 = 0.530$
$(D_1/2D_2) = 0.86$

ARCTEC CANADA LIMITED

ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452 C
PROJECT MV KALVIK PROPULSION
SUBJECT INTERMEDIATE BEARING CALIB.

SHEET ..... OF .....
DATE 24/11/8
BY AL
CH'K. BY

CHANNEL ID	LOCATION	CALIB	OFFSET
BR41S	FRAME 41 STARBOARD	9 KN/μE	0
BR 41 P	FRAME 41 PORT	9 KN/μE.	0
BR 50S	FRAME 50 STARBOARD	8 KN/μE	0
BR50P	FRAME 50 PORT	8 KN/μE	0
BR 55S	FRAME 55 STARBOARD	8 KN/μE	0
BR55P	FRAME 55 PORT	8 KN/μE	0

ALL OF THE ABOVE GAUGES WERE CONFIGURED AS FOLLOWS:

$V_E = 10$ Volts (EXCITATION VOLTAGE)
$N = 1$ ACTIVE ARM (NUMBER OF ACTIVE ARMS)
$G = 2000 = A$ (AMPLIFIER GAIN)
$GF = 2.01 = K$ (STAIN GAUGE FACTOR)

$$\mu E/V_{out} = 4/[(N)(V_E)(A)(K)] = 4/[(1)(10)(2000)(2.01)$$

$$\mu E/Volt = \underline{99.5}$$

$$\mu E/AD = (99.5)(0.005) = 0.4975$$

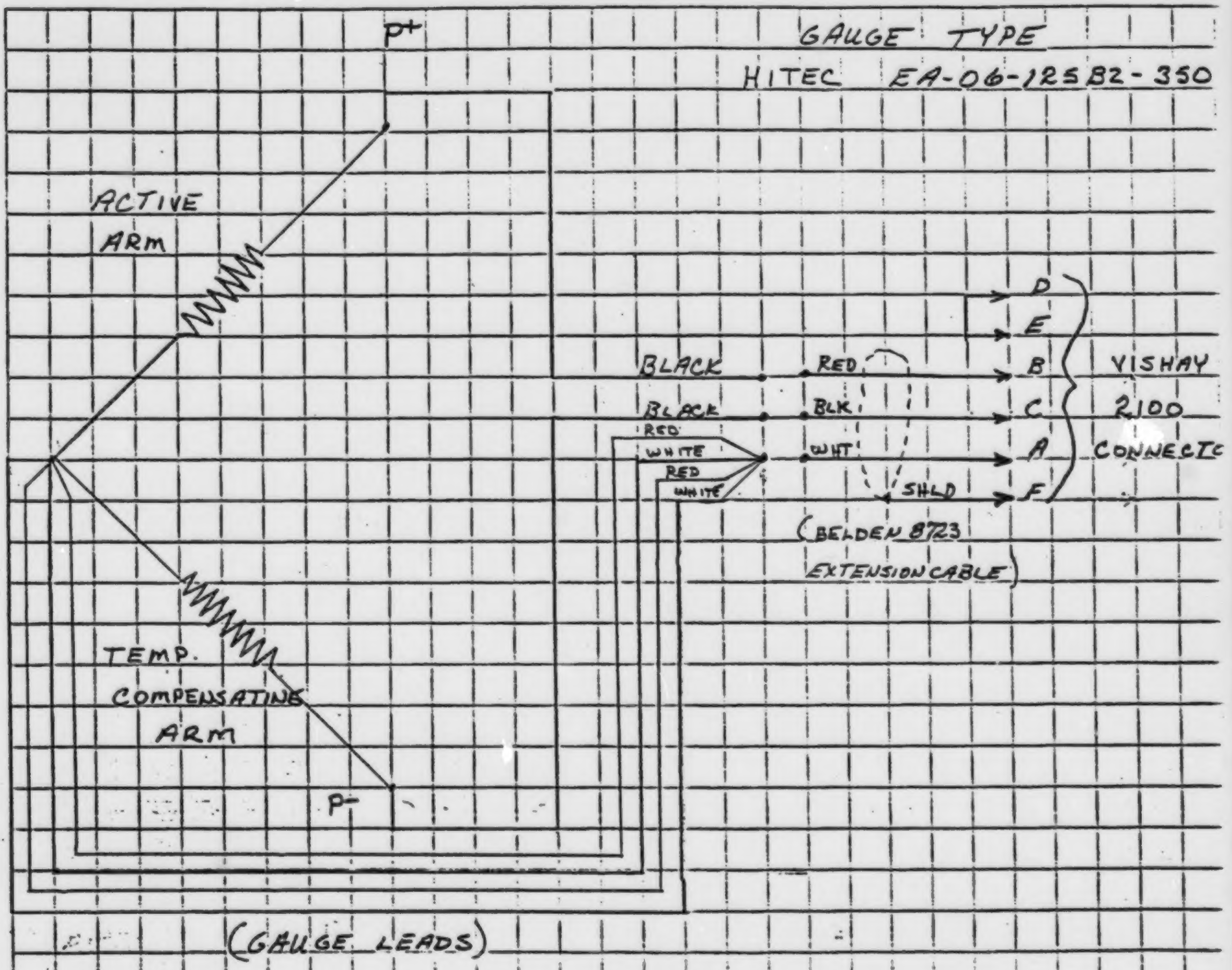
0

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

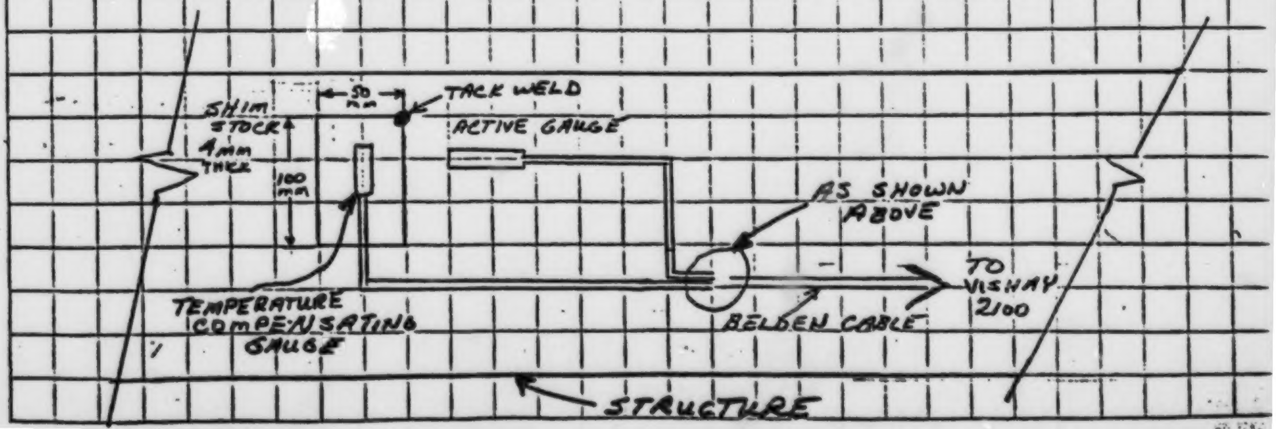
JOB. NO. 2452C
PROJECT
SUBJECT WIRING SCHEMATIC FOR GLOBAL BENDING GAUGES AND BEARING LOAD GAUGES

SHEET .... OF ....
DATE AUG 5,
BY Al
CH'K. BY

GAUGE TYPE
HITEC EA-06-125B2-350



HALF BRIDGE TEMPERATURE COMPENSATING LAYOUT DIAGRAM



ARCTEC CANADA LIMITED

ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2952

PROJECT M.V. KALVIK

SUBJECT INT BEAR LOAD CALIBRATIONS.

SHEET .... OF ....

DATE 86/09/11

BY DNBL

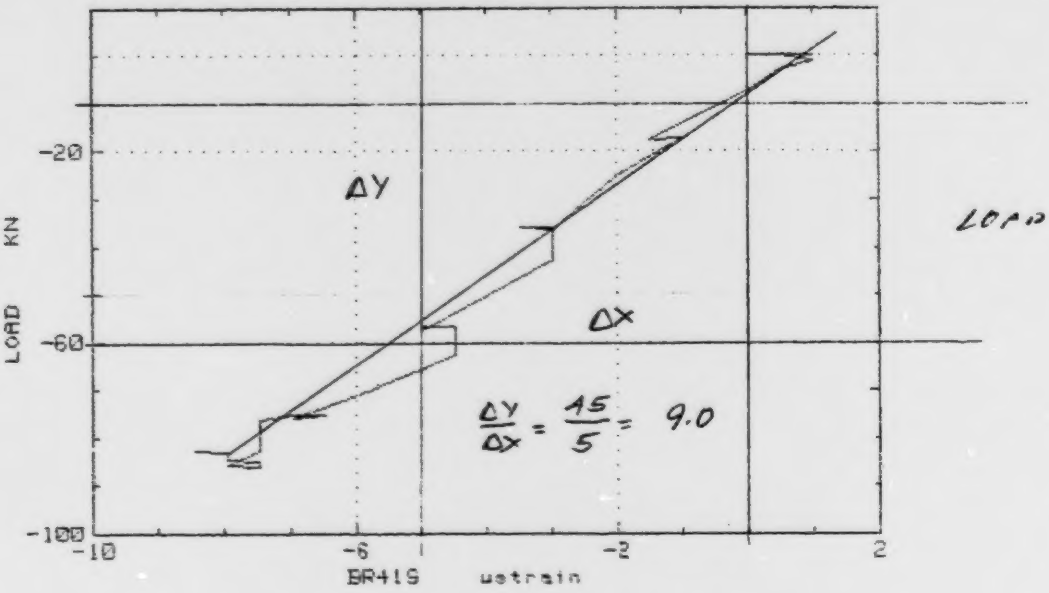
CH'K. BY ....

BR A1-3 – PUSH DOWN ON BRG. ✓ O.K.

CALIB = 9 KN/με

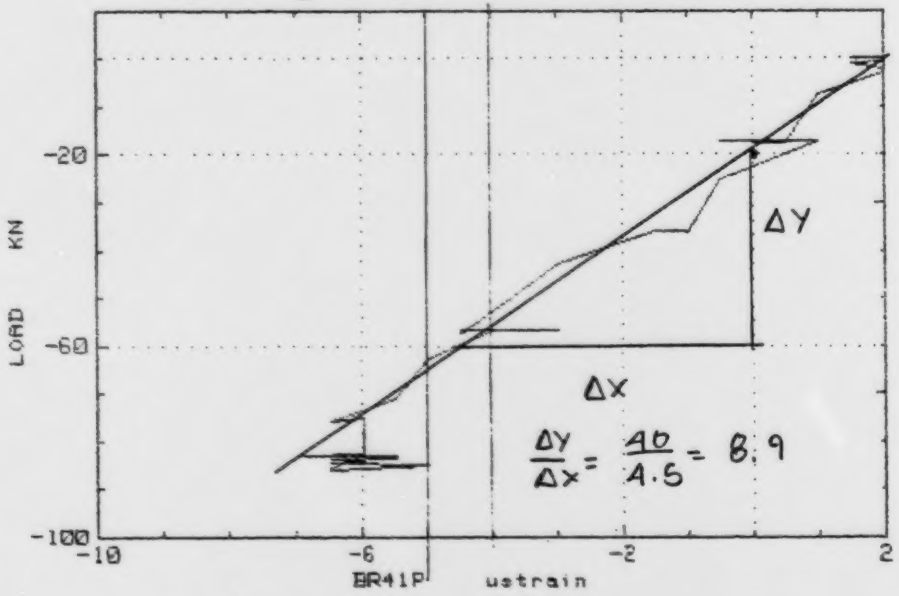
CALIB = (9)(0.4975) = 4.475 KN/AD

1986 M.V. KALVIK PROP. TESTS- ARCTEC CANADA LTD.
EVENT BR41_3 DATE/TIME: 18 Sep 1986 / 16:04:04



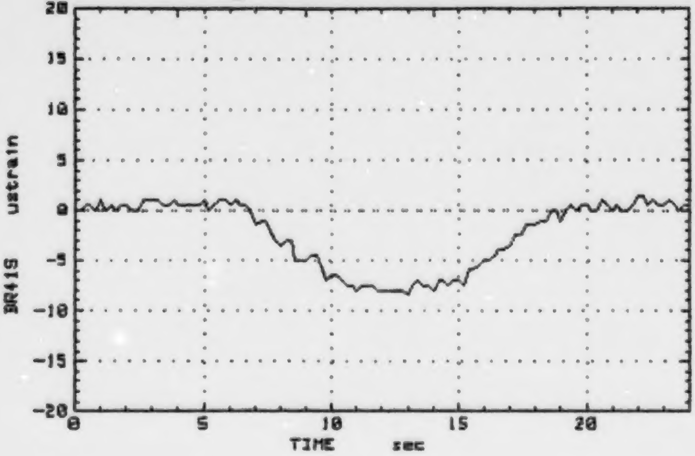
LOAD ON

1986 M.V. KALVIK PROP. TESTS- ARCTEC CANADA LTD.
EVENT BR41_3 DATE/TIME: 18 Sep 1986 / 16:04:04

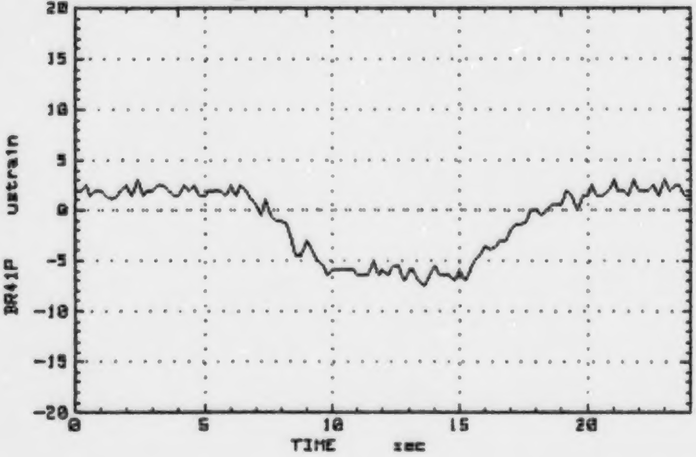


LOAD ON

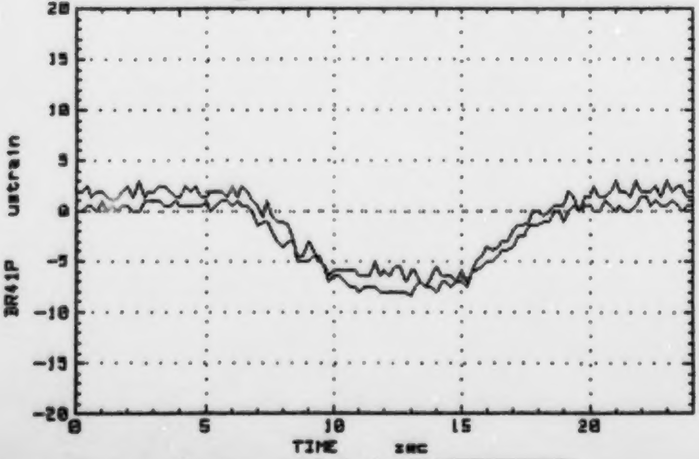
1986 M.V. KALVIK PROP. TESTS- ARCTEC CANADA LTD.
EVENT BR41_3 DATE/TIME: 18 Sep 1986 / 16:04:04

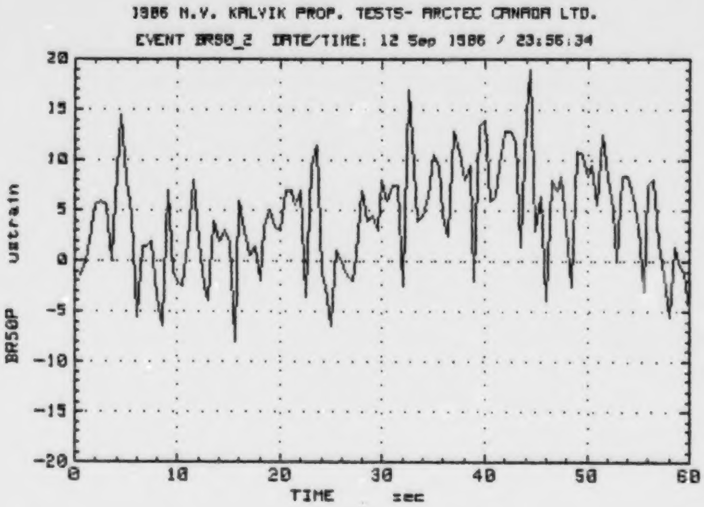


1986 M.V. KALVIK PROP. TESTS- ARCTEC CANADA LTD.
EVENT BR41_3 DATE/TIME: 18 Sep 1986 / 16:04:04



1986 M.V. KALVIK PROP. TESTS- ARCTEC CANADA LTD.
EVENT BR41_3 DATE/TIME: 18 Sep 1986 / 16:04:04



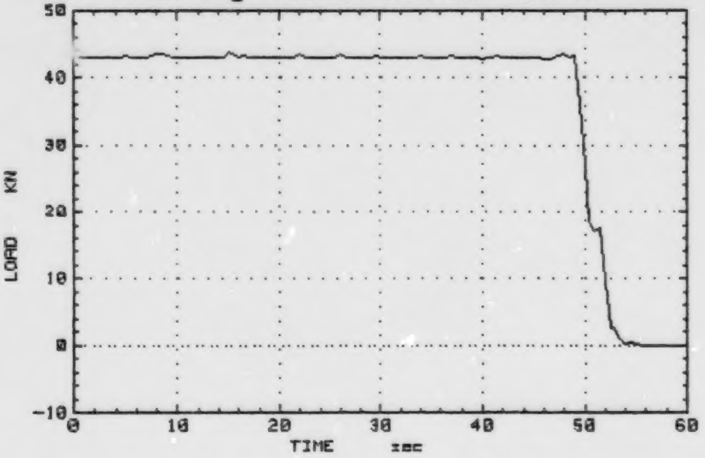


1986 M.V. KALVIK PROP. TESTS- ARCTEC CANADA LTD.

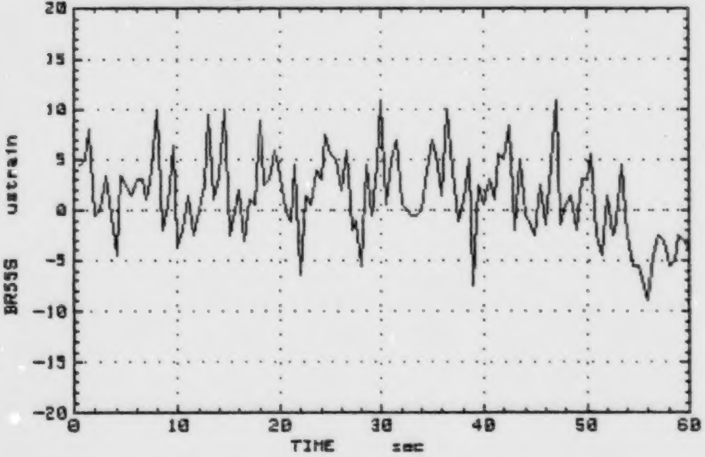
EVENT BR50_2 DATE/TIME: 12 Sep 1986 / 23:56:34

$$\frac{5\mu\varepsilon}{40kN}$$

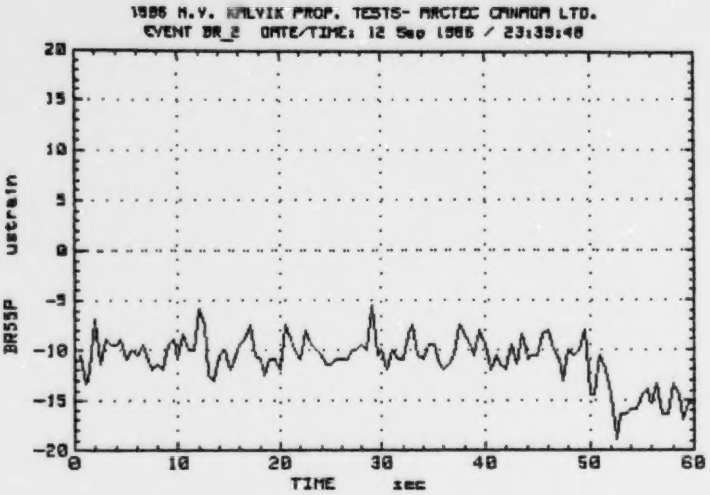
1986 M.V. KALVIK PROP. TESTS- ARCTEC CANADA LTD.
EVENT BR55_2 DATE/TIME: 12 Sep 1986 / 23:35:48



1986 M.V. KALVIK PROP. TESTS- ARCTEC CANADA LTD.
EVENT BR55_2 DATE/TIME: 12 Sep 1986 / 23:35:48



$\frac{5 \mu\varepsilon}{40 \text{ KN}}$.



$$\frac{5\,\mu\varepsilon}{40\,kN}$$

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. ....

PROJECT ....

SUBJECT ESTIMATE OF STRAIN -
AFT FLYWHEEL BEARING

SHEET 1 OF 2

DATE 7/8/86

BY

CH'K. BY ....

BR50 P+S

SAME BR55 P+S

CALCULATED REACTION $-R_4 = 0.237$ MN.

ASSUME THE LOAD OF 1g WILL DOUBLE THE REACTION, IE FORCE APPLIED IS 0.237 MN.

WEBS + GIRDERS 0.020 mm THICK

TOTAL COMPRESSION AREA.

$3 \times 0.020 \times 1m + 2 \times 0.020 \times 1m = 0.1 m^2$ ✓

STRESS IN THE WEBS IS:

$\sigma = F/A = \frac{0.237 MN}{0.1 m^2} = 2.37$ MPa ✓

$STRAIN = \frac{\sigma}{E} = \frac{2.37 \times 10^6}{2.1 \times 10^{11}} = 1.13\ 10^{-5} = \underline{\underline{11.3\ 10^{-6}}}$ ✓

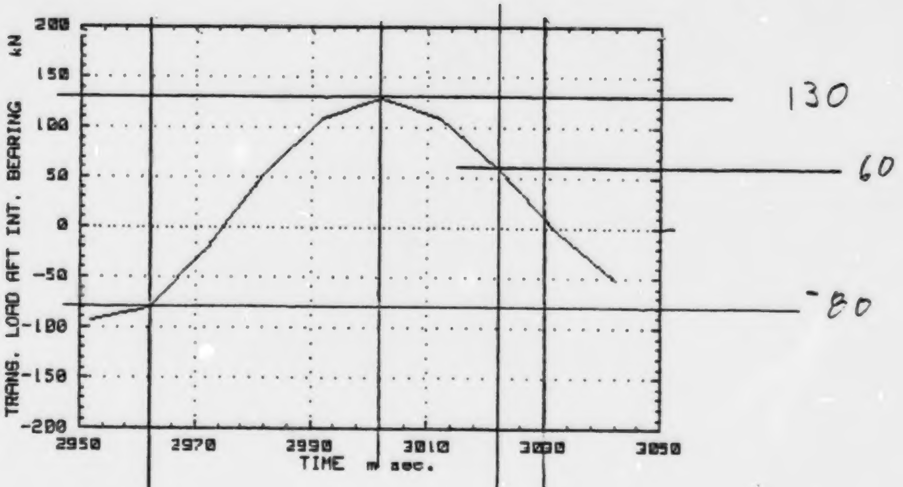
FIRST INTERM BRG BR 41 P+S

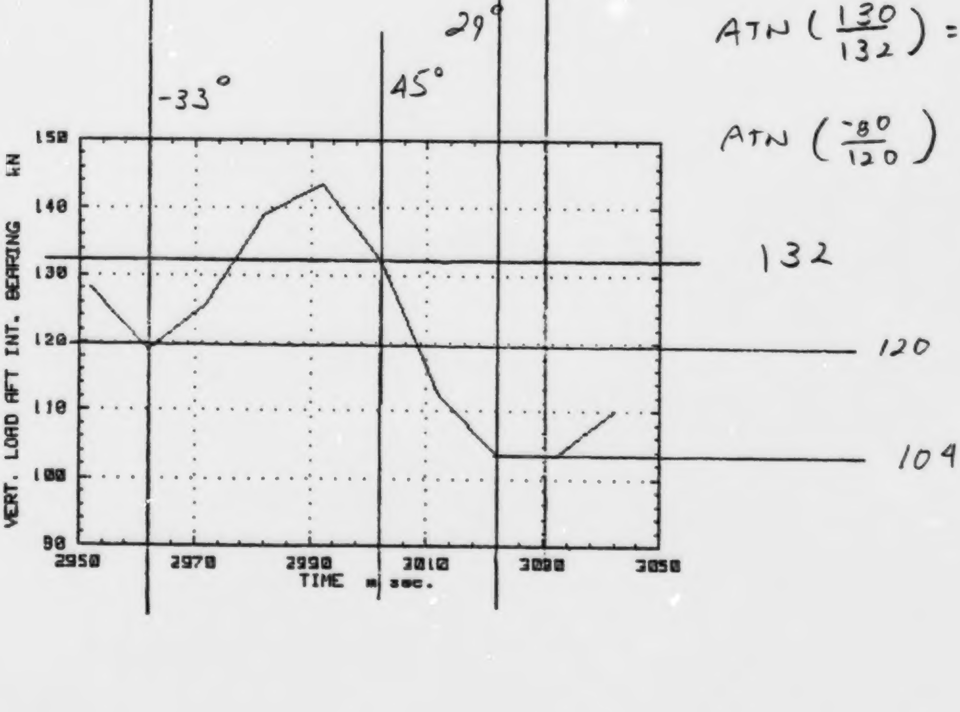
$2 \times 0.040 \times 1.5m + 3 \times .580 \times 0.040 = 0.2 m^2$ ✓

Load of 1g gives $- 0.167$ MN

Stress is: $0.167/0.2 = 0.83 \times 10^6$ MPa ✓

Strain $\frac{0.83\ 10^6}{2.10\ 10^{11}} = \underline{\underline{4 \times 10^{-6}}}$

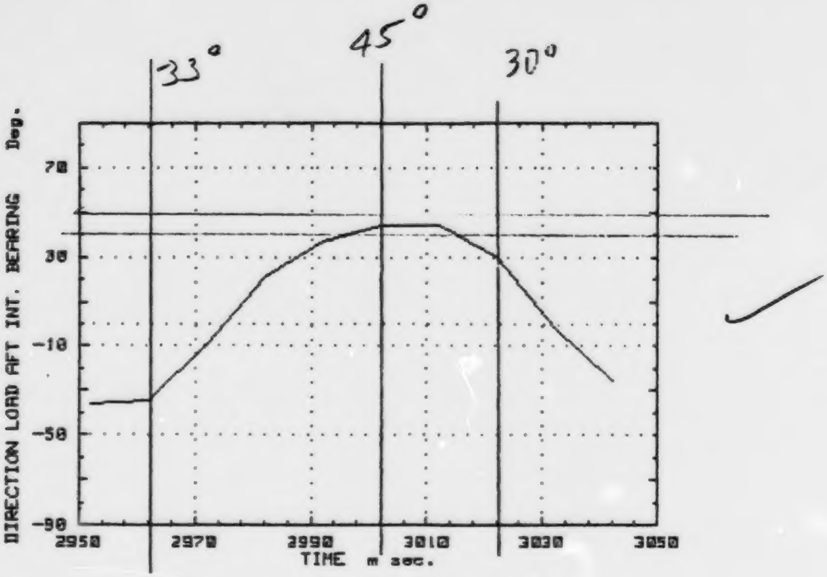




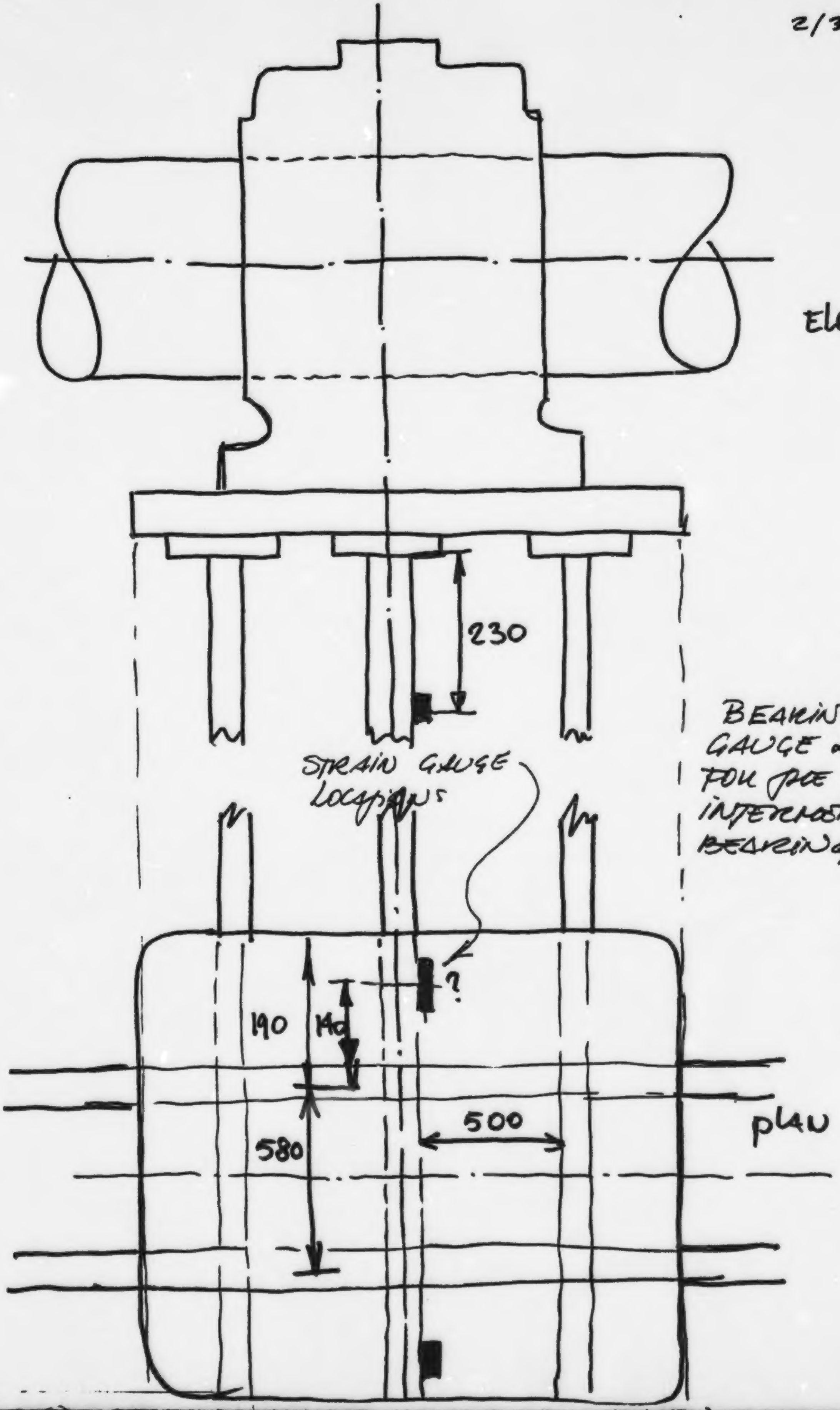
$ATN\left(\frac{60}{104}\right) = 29°$

$ATN\left(\frac{130}{132}\right) = \underline{\underline{45°}}$

$ATN\left(\frac{-80}{120}\right) = (-33°)$

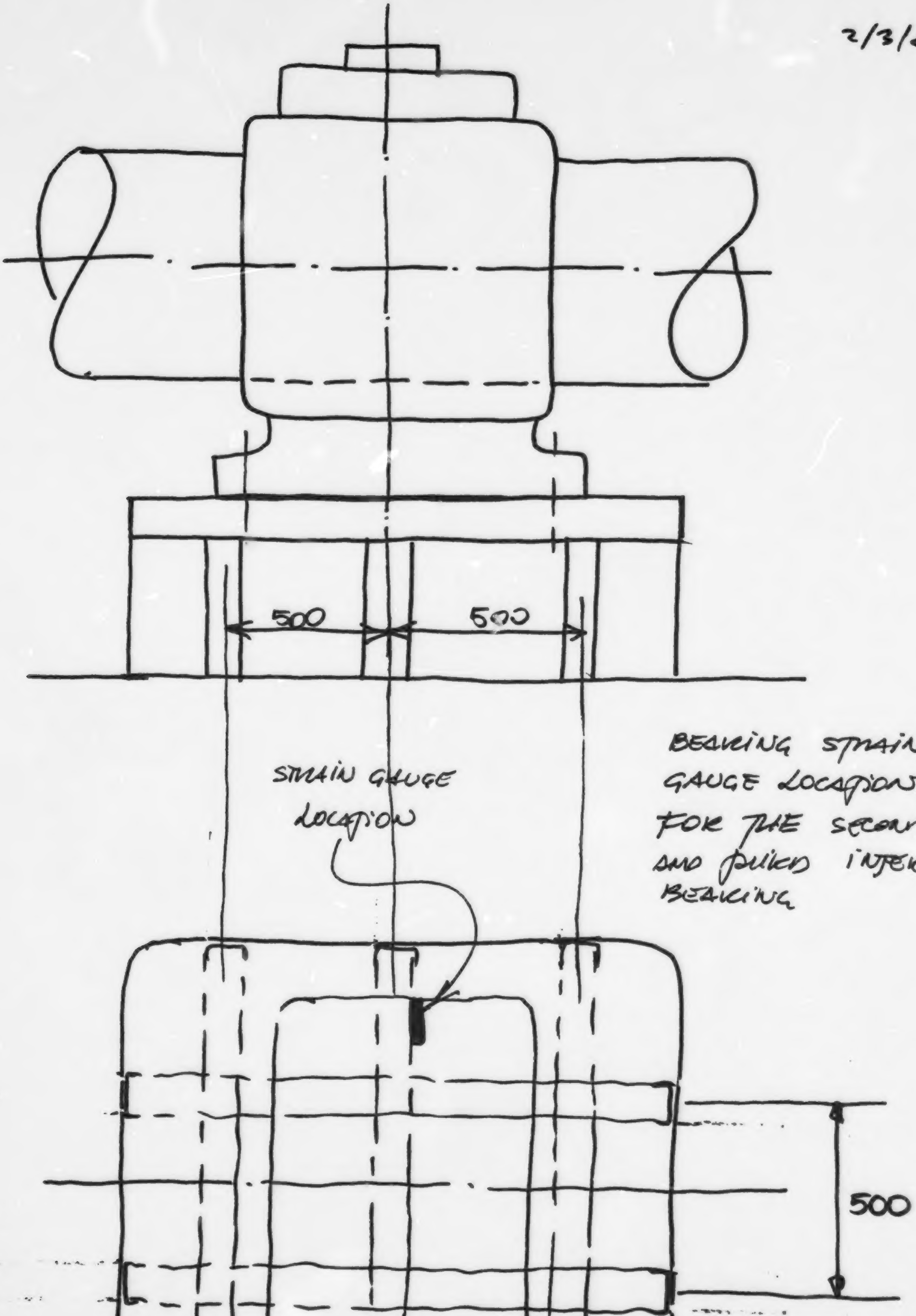

33°
45°
30°
DIRECTION LOAD AFT INT. BEARING Deg.
70
30
-10
-50
-90
2950
2970
2990
3010
3030
3050
TIME m sec.

2/3/87
VL



BEARING STRAIN GAUGE LOCATION FOR THE FIST INTERMEDIATE BEARING

2/3/87
VL



BEARING STRAIN GAUGE LOCATIONS FOR THE SECOND AND THIRD INTERMEDIATE BEARING

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT M.V. KALVIK PROPULSION
SUBJECT THRUST CALIBRATION

SHEET ..... OF .....
DATE FEB 18/8
BY
CH'K. BY

COMPONENT	CALIBRATION FACTOR	OFFSET
THRUST	26.9 μE/VOLT	0

THE CALIBRATION OF THIS SIGNAL WAS CONDUCTED BY SHUNTING VARIOUS RESISTORS ACROSS ONE ARM OF THE BRIDGE CONFIGURATION.

ARCTEC CANADA LIMITED

ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452C

PROJECT MV KALVIK PROPULSION

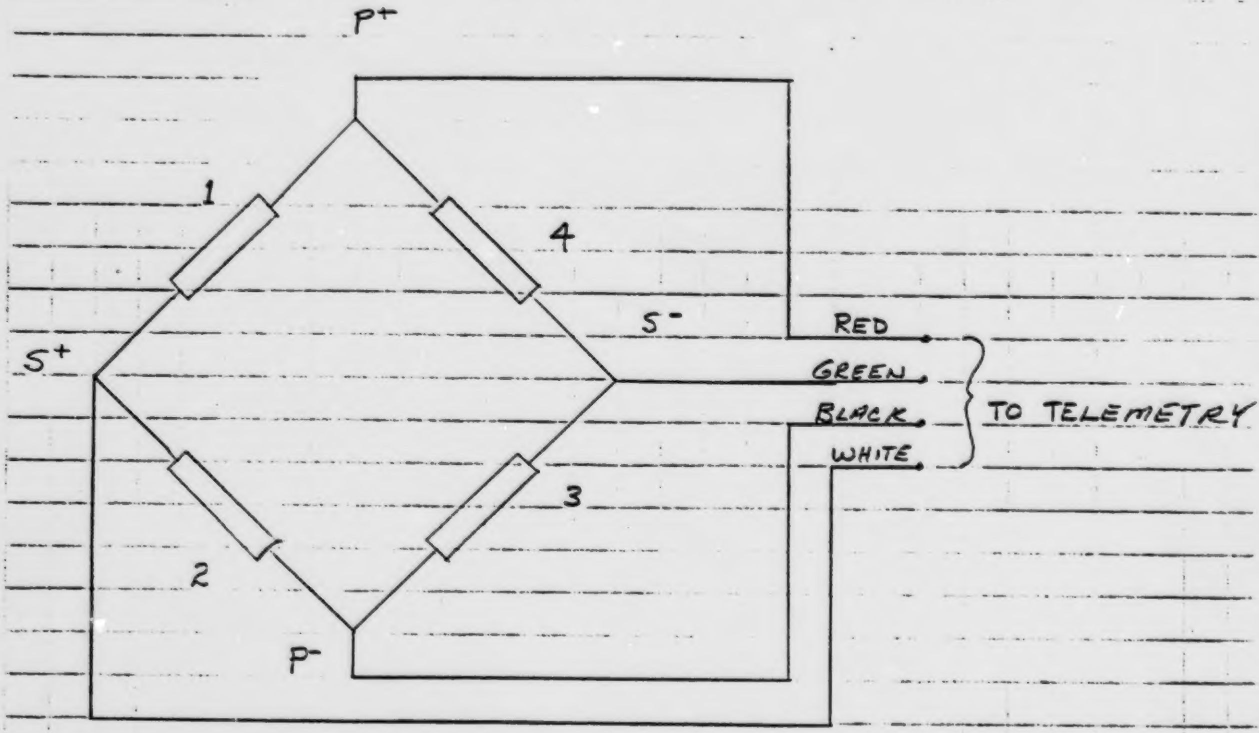
SUBJECT THRUST GAUGE SCHEMATIC AND CONFIGURATION

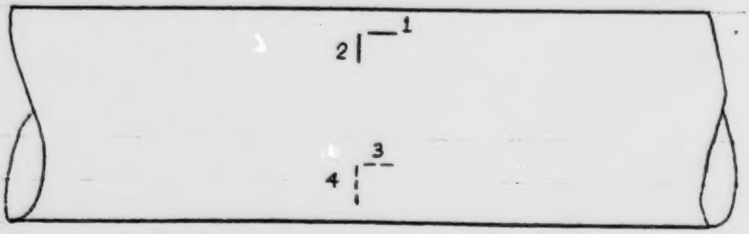
SHEET 1 OF 1

DATE AUG. 14

BY al

CH'K. BY



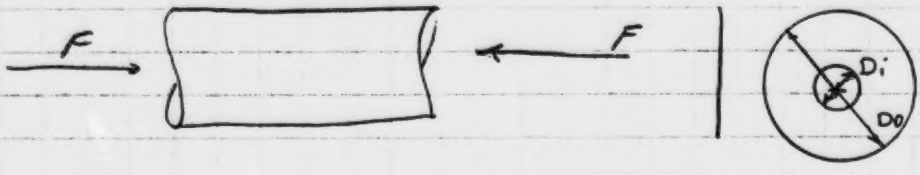


ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT
SUBJECT THRUST CALIB

SHEET ... OF ...
DATE 86/11/03
BY DNBL
CH'K. BY

$1AD = 26.9\ \mu\varepsilon / \text{VOLT.} \Rightarrow 0.1345\ \mu\varepsilon/AD$

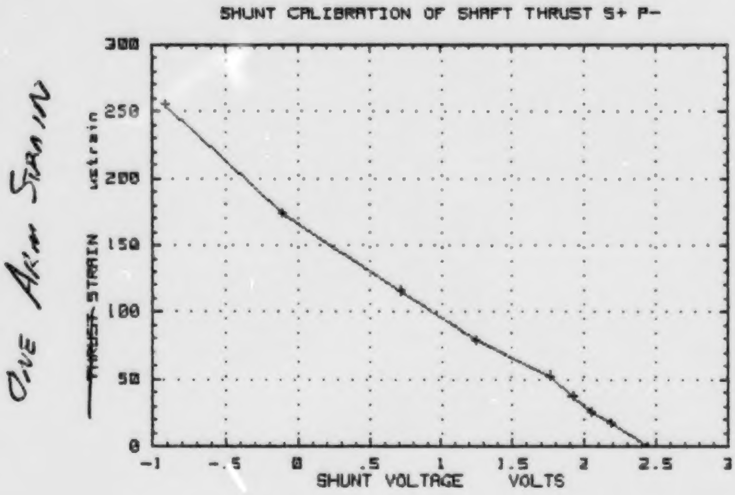


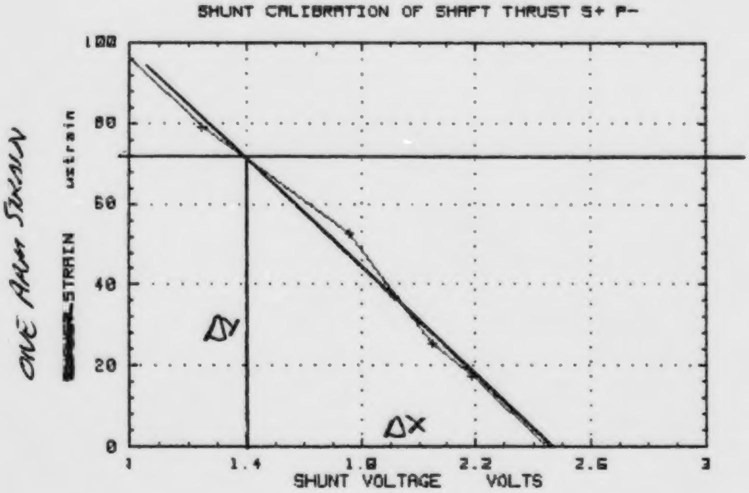
$\sigma = \varepsilon E = F/A$

$A = (\pi/4)(D_o^2 - D_i^2) = (\pi/4)(0.47^2 - 0.19^2) = 0.1451\ m^2$

$F = A\varepsilon E = (0.1451)(0.1345)(2.09\times10^{11})\ (N/AD)$

$F = 0.00408\ MN/AD$

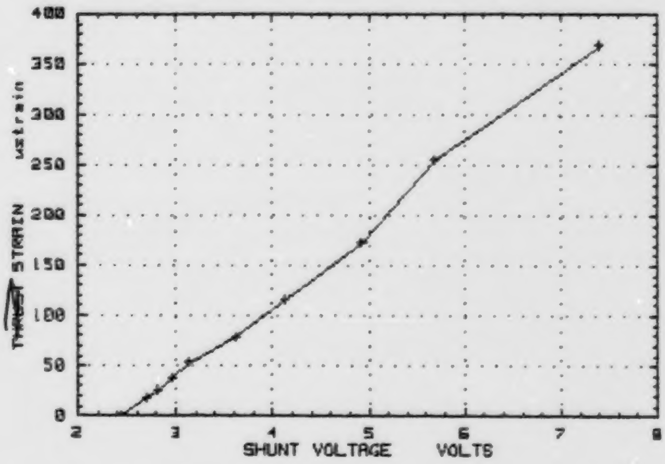




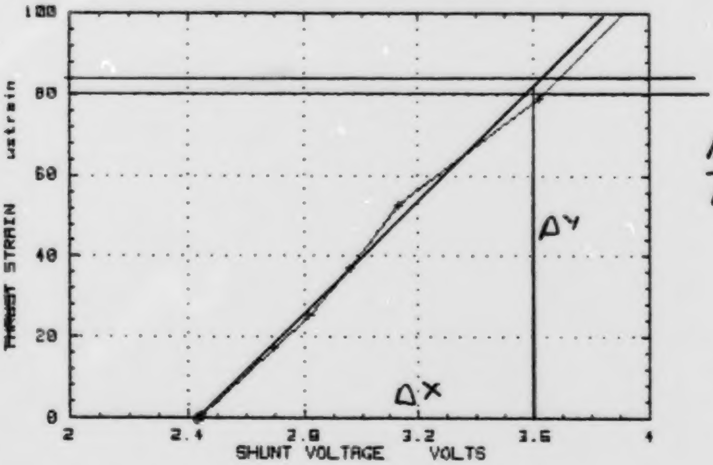
$$\frac{\Delta Y}{\Delta X} = \frac{72}{1.05} = 68.6\ \mu s/\text{volt}/\text{arm}$$

2.6 ACTIVE ARMS $\Rightarrow 68.6/2.6 = 26.4\ \mu\Sigma/\text{volt}$

SHUNT CALIBRATION OF SHAFT THRUST S+ P+



SHUNT CALIBRATION OF SHAFT THRUST S+ P+



$$\frac{\Delta Y}{\Delta X} = \frac{82}{1.15} = 71.3 \ \mu\varepsilon/\text{VOLT}/\text{CM}$$

2.6 ACTIVE ARMS $\Rightarrow \frac{71.3}{2.6} = 27.4 \ \mu\varepsilon/\text{VOLT}$

ARCTEC CANADA LIMITED

ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT
SUBJECT THRUST CALIBRATIONS
SHEET ... OF ...
DATE DNB.C
BY 86/11/20
CH'K. BY

THRUST CALIBRATIONS.

SHUNT CAL. 0.816 MN/VOLT
OFFSET VOLTAGE = 1.9 VOLTS. (RAM 6)

BOLLARD PUSH 3.0 ± 0.15 VOLTS - THRUST
FULL AHEAD 460 ± 10 KNm - TORQUE
19.3 ± 0.5 DEG - PITCH
130 - RPM

BOLLARD PUSH 2.6 ± 0.15 VOLTS - THRUST
½ AHEAD 210 ± 10 KNm - TORQUE
11.8 ± 0.4° DEG. - PITCH
130 - RPM

PROPELLER CURVES = .869 MN. FULL AHEAD
THRUST = .466 MN ½ AHEAD

VOLTAGE OFFSET FROM PROP CURVES ⇒ 0.995 MN/VOLT
⇒ 0 MN ⇒ ΔV = -0.468 VOLTS
⇒ V OFFS = 2.6 - .468 = 2.13 VOLTS

PROPELLER THRUST = 0.898 MN FULL AHEAD
FROM SHAFT INST = 0.571 MN ½ AHEAD.

% DROP FROM FULL AHEAD - ½ AHEAD → 37% INST.
47% CURVES

JOB. NO. 2452
PROJECT
SUBJECT SHUNT CALIBRATION

SHEET ... OF ...
DATE 86/10/29
BY DNBL
CH'K. BY

THRUST

SHUNT R ($M\Omega$)	S^+, P^- (VOLTS)	S^+, P^+ (VOLTS)	STRAIN ($\mu\varepsilon$)
	2.44	2.44	0
10	2.19	2.70	17.3
6.8	2.05	2.82	25.5
4.7	1.92	2.96	36.9
3.3	1.76	3.13	52.5
2.2	1.25	3.62	78.8
1.5	0.72	4.19	115.5
1.0	-0.10	4.93	173.2
0.68	-0.905	5.70	255
0.47	SAT	7.41	368

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT M.V. KALVIK
SUBJECT TORQUE / THRUST STRAIN
SHEET ...... OF ......
DATE 86/08/11
BY DNBC
CH'K. BY ......

THRUST STRAIN

NOMINAL THRUST AHEAD = 800 kN = 0.8 MN.

MAX THRUST AHEAD ≐ 4.0 MN.

OUTSIDE DIA. = .470 mm
INSIDE DIA. = .19 mm

AREA = $(\pi/4)(.47^2 - .19^2) = 0.145\,m^2$

MAX. THRUST STRESS = $4/0.145 = 27.6$ MPa

E = MODULUS = $2.1 \times 10^{11}\ N/m^2$

MAX THRUST STRAIN = $27.6 \times 10^6 / 2.1 \times 10^{11} = \underline{131\,\mu\varepsilon}$

MAX THRUST STRAIN = $\boxed{131\,\mu\varepsilon}$ ←

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452 C
PROJECT M.V. KALVIK
SUBJECT TORDUCTOR CALIBRATION

SHEET ...... OF ......
DATE Feb 18/[illegible]
BY Al
CH'K. BY

COMPONENT	CALIBRATION FACTOR.
ASEA TORQUE METER	766 KN.m/Volt.

THE SIGNAL IS TAKEN FROM THE ASEA TORQUE METER IN THE SHIPS CONTROL ROOM.

ARCTEC CANADA LIMITED

ENGINEERING DESIGN CALCULATIONS

JOB. NO.
PROJECT
SUBJECT

SHEET ...... OF ......
DATE
BY
CH'K. BY

TORDUCTOR CALIBRATION.

STBD.

DB 9-10 6.02-6.19 VOLTS ASEA
0.637 VOLTS AD200 CARD

CAL = (6.1 VOLTS)(80 KNm/VOLT) / 0.637 VOLTS

CAL = 766 KN·m/VOLT × 0.005 VOLTS/AD

CAL = 3.83 KNm/AD.

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT
SUBJECT TORDUCTOR CALIB
SHEET ... OF ...
DATE 86/09/1[illegible]
BY D.N.B.C
CH'K. BY

STARBOARD SHAFT

VOLTAGE (BD 11-12) (VOLTS) ×10	TORQUE (KN·m)	VOLTAGE (BD 9-10)* VOLTS ×10
1.55	90	1.15
3.70	216	2.76
6.08	354	4.53
8.12	487	6.05
9.47	563	7.05

PORT SHAFT

VOLTAGE (BD11-12) (VOLTS ×10)	TORQUE (KN·m)	VOLTAGE (BD 9-10)*
1.864	108	1.38
4.207	252	3.12
6.17	370	4.57
8.10	489	6.00
8.67	516	6.92

USE THIS ONE → CLOSEST TO DIAL GAUGE IN CONTROL ROOM.

ARCTEC CANADA LIMITED

ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2952

PROJECT M.V. KALVIK

SUBJECT BOLLARD PUSH

SHEET 2 OF 2

DATE 86/DO1

BY DNBC

CH'K. BY

V2 AHEAD BOLLARD PUSH

		PORT	STBD.
TORDUCTOR	DB 9-10	2.8 V	3.15 V
	DB 11-12	3.8 V	4.22 V

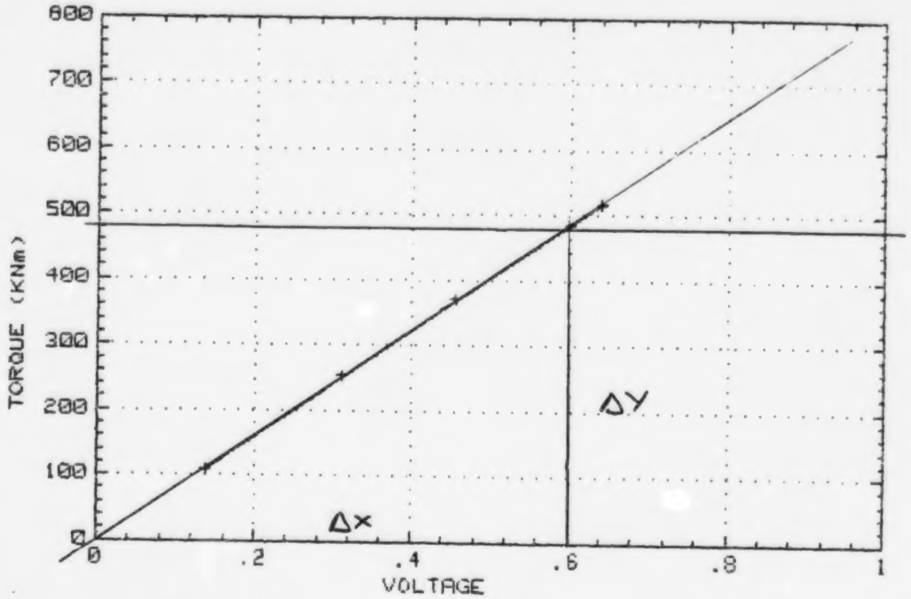
PITCH	PORT	14.1°
	STBD.	14.1°

RUDDER ANGLE

CONTROL ROOM CONSOLE

	PORT	STBD
RPM	130	130
PITCH (POSITION)	5	5
TORQUE (kN·m)	292	270
POWER (kW)	3000	3900

ASEA TORQUCTOR CALIBRATION PORT SHAFT BO 9-10



$$\frac{\Delta Y}{\Delta X} = \frac{480}{0.6} = 800 \text{ KN}\cdot\text{m/VOLT}$$

$$\text{CALIB} = (800)(0.005) = 4 \text{ KN}\cdot\text{m/AD}$$

ARCTEC CANADA LIMITED

ENGINEERING DESIGN CALCULATIONS

JOB. NO.
PROJECT
SUBJECT SHAFT BENDING CALIBRATIONS
SHEET ... OF ...
DATE
BY
CH'K. BY

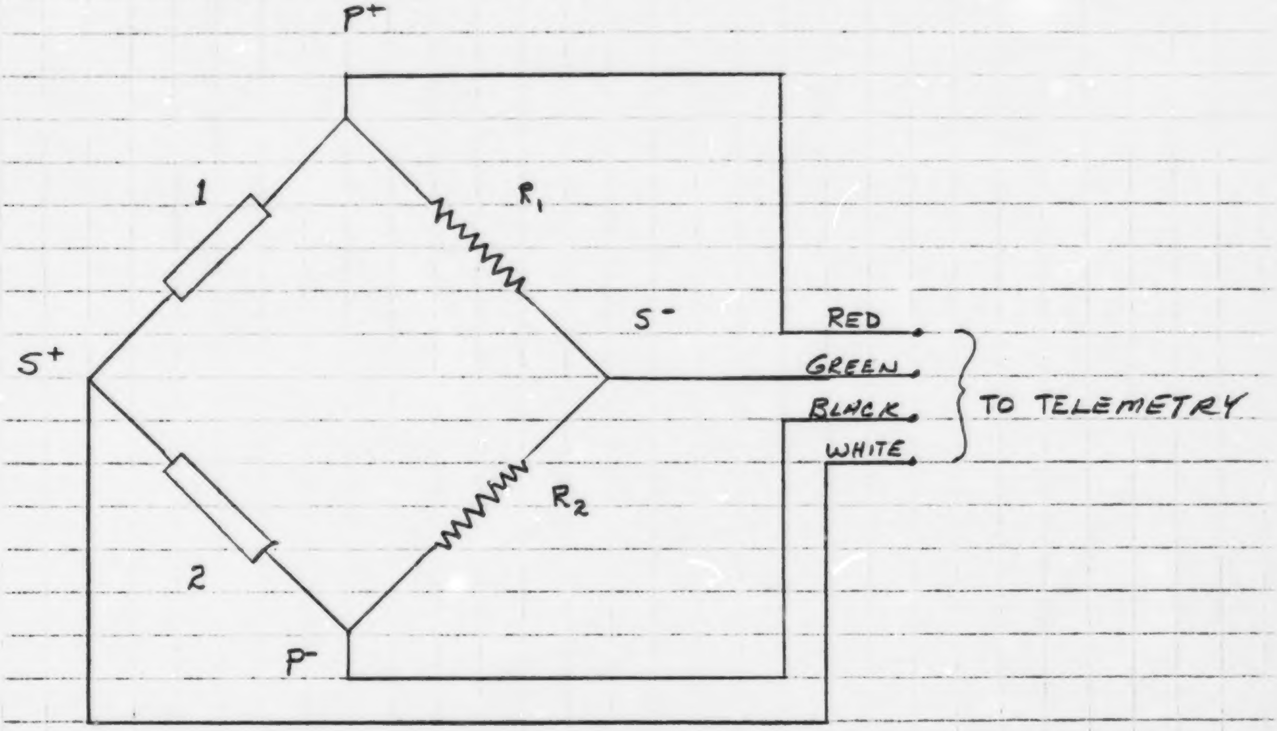
COMPONENT	CALIBRATION FACTOR	OFFSET
SB 36		
SB 39	110 $\mu\varepsilon$/Volt	0
SB 46	200 $\mu\varepsilon$/Volt	0

THESE CHANNELS ARE A STRAIN GAUGE HALF BRIDGE CONFIGURATION USING A TELEMETRY SYSTEM TO TRANSMIT THE SIGNAL WHILE THE SHAFT IS TURNING. ALTHOUGH GOOD SIGNALS WERE AVAILABLE FROM SB 39 AND SB 46 FOR THE SHUNT CALIBRATION, SB 36's SIGNAL WAS QUITE "NOISEY" AND PROVED TO BE UNRELIABLE.

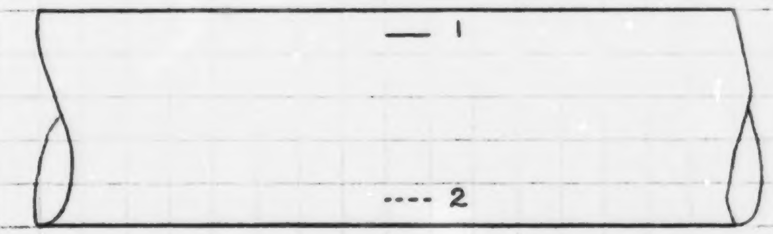
ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452C
PROJECT MV KALVIK PROPULSION
SUBJECT SHAFT BENDING GAUGES SCHEMATIC AND CONFIGURATION SB36, SB39, SB46

SHEET 1 OF 1
DATE Aug 14/1
BY
CH'K. BY

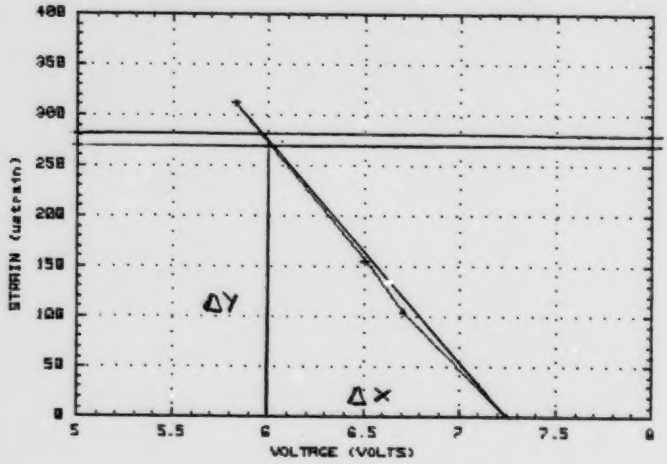


NOTE: R_1 & R_2 are completion resistors



SB39

SHUNT CALIBRATION FOR SB36 (POS 8-3)



$$\frac{\Delta Y}{\Delta X} = \frac{275}{1.25} = 220\ \mu\varepsilon/\text{VOLT}/\text{ARM}$$

2 ACTIVE ARMS

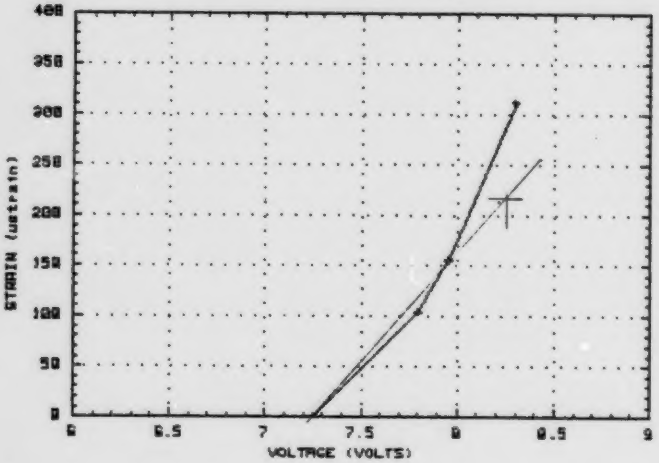
$\Rightarrow$ 110 $\mu\varepsilon$/VOLT ✓

$\Rightarrow$ CAL = 0.55 $\mu\varepsilon$/AD

OFF ≈ (7.25 VOLTS)/0.005 = 1450

SB39

SHUNT CALIBRATION FOR SB38 (POS 4-8)



ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT
SUBJECT SHUNT CAL SB 46

SHEET ..... OF .....
DATE 86/11/10.
BY D.N.B.C.
CH'K. BY

CAL 1 = 182 $\mu\varepsilon$/VOLT

CAL 2 = 216 $\mu\varepsilon$/VOLT

CAL = $(182+216)/2$ = 200 $\mu\varepsilon$/VOLT

OFFS = $(^{-}38+{-30})/2 = {^{-}34}$ m VOLTS

CAL = $(200)(0.005)$ = 1.0 $\mu\varepsilon$/AD

OFFS = $^{-}.034$ VOLTS/0.005 = $^{-}6.8$ AD

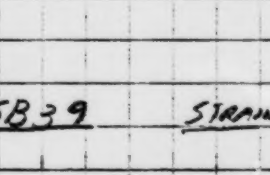
JOB. NO. 2452
PROJECT
SUBJECT SHUNT CALIBRATION

SHEET ... OF ...
DATE 86/10/29
BY DNBL/MH
CH'K. BY

SB 36 TRANS. BOX 94 MHZ. LBL 20613

SHUNT (POS.)	STRAIN (με)		VOLTS (AVG.)		|ΔVOLTS|		με/VOLT/ARM	
0	0	-0.94	(-.88)	-0.82	0	0	0	0
1	109	-0.91	(-.92)	-0.93	0.03	0.11	3500	954
2	155	-0.88	(-.89)	-0.90	0.06	0.08	2580	1938
3	311	-0.30	(-.31)	-0.32	0.69	0.50	486	622
4	104	-0.82	(-.81)	-0.79	0.12	0.03	875	3500
5	155	-0.79	(-.77)	-0.75	0.15	0.13	1033	1192
6	311	/		-0.14		0.68	/	457

SB39	STRAIN	VOLTS	|ΔVOLTS|	με/VOLT/ARM
0	0	7.25	0	0
1	109	6.71	0.54	194
2	155	6.51	0.74	209
3	311	5.83	1.42	219
4	109	7.80	0.65	162
5	155	7.96	0.71	218
6	311	8.30	1.05	296



LOOKING DOWN ON TRANSMITTER BOX

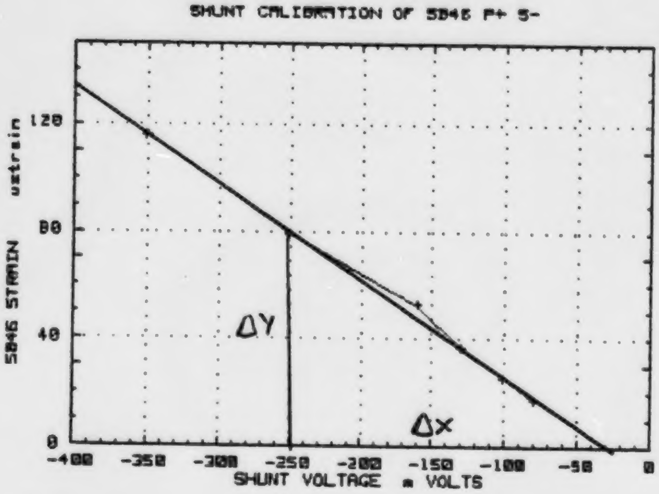
ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT
SUBJECT SHUNT CALS

SHEET ... OF ...
DATE 86/09/15
BY DNB/CIM
CH'K. BY

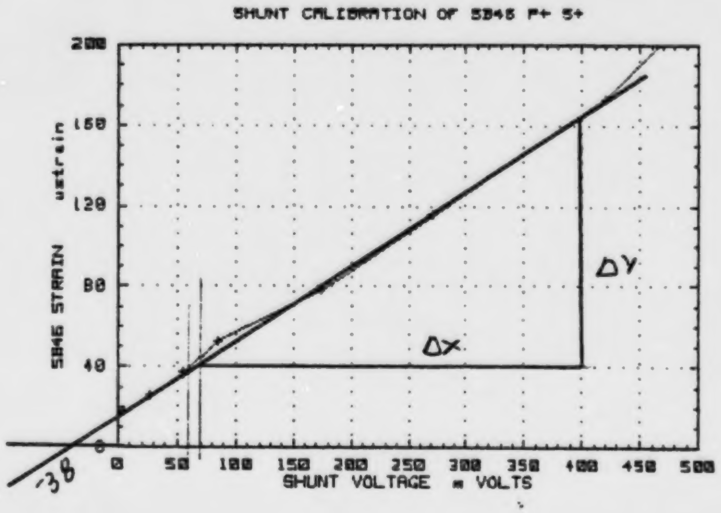
SB 46

SHUNT R (MΩ)	P^-, S^+ (VOLTS)	S^-, P^+ (VOLTS)	STRAIN (με)
10	-0.08	0.005	17.3
6.8	-0.101	0.027	25.5
4.7	-0.130	0.055	36.9
3.3	-0.160	0.085	52.5
2.2	-0.250	0.175	78.8
1.5	-0.350	0.271	115.5
1.0	-0.500	0.420	173.2
0.68	-0.697	0.566	255
0.47	-0.977	0.890	368
0.33	-1.336	1.238	525
0.22	-2.18	2.05	786
0.15	-3.07	2.87	1152
0.10	-4.97	3.65	1726
0.068	SAT	3.75	2535



$$\frac{\Delta Y}{\Delta x} = \frac{80}{0.22} = 363\ \mu\varepsilon/\text{VOLT}/\text{ARM}$$

$$\Rightarrow 182\ \mu\varepsilon/\text{VOLT}$$



$$\frac{\Delta Y}{\Delta X} = \frac{143}{0.330} = 433\ \mu\varepsilon/\text{volt}/\text{arm}$$

$\Rightarrow$ 216 $\mu\varepsilon$/volt

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452C
PROJECT M/V KALVIK PROPULSION
SUBJECT ACCELEROMETER CALIBRATIONS

SHEET .... OF ....
DATE FEB 18/
BY
CH'K. BY

COMPONENT	CALIBRATION FACTOR	OFFSET
ACV34P	10.64 m/s² / VOLT	0
ACV F	10.55 m/s² / VOLT	0
ACVS	8.5 m/s² / VOLT	0

THESE ACCELEROMETERS WERE CALIBRATED PRIOR TO INSTALLATION. THE CALIBRATION TABLE AND LOCATIONS OF EACH ACCELLEROMETER FOLLOW.

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2952
PROJECT M.V KALVIK
SUBJECT ACCELEROMETER CALIBRATIONS

SHEET 2 OF 2
DATE 86/09/02
BY DNBC
CH'K. BY

ACV34P: $(2)(9.81\ m/s^2) = 1.036 + 0.809$ VOLTS

$1\ m/s^2 = 0.0940$ VOLTS

CALIB $= 0.0532\ m/s^2$ /AD.

ACVF $(2)(9.81\ m/s^2) = 0.850 + 1.01$ VOLTS

$1\ m/s^2 = 0.0948$ VOLTS

CALIB $= 0.0527\ m/s^2$ /AD

ACV34S: $(2)(9.81) = 1.025 + 1.285$

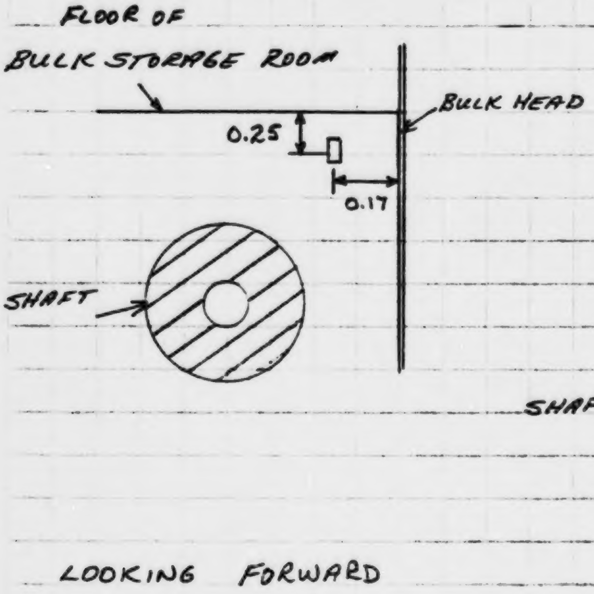
$1\ m/s^2 = 0.1177$ VOLTS

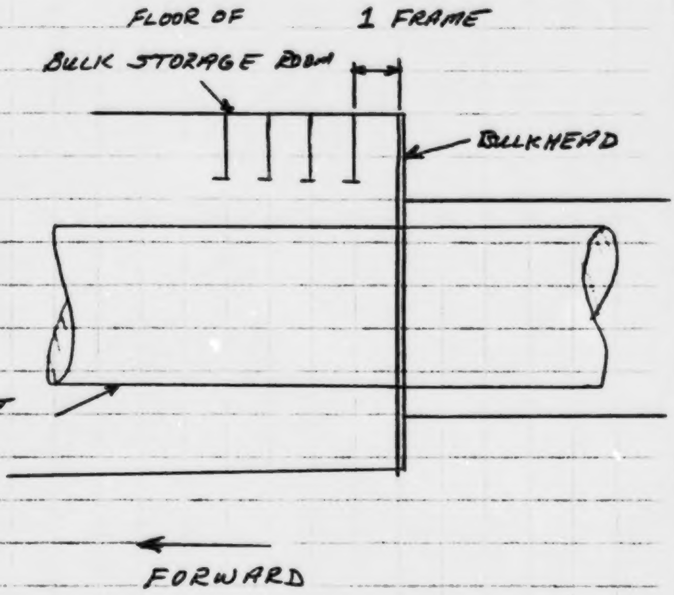
CALIB $= 0.0425\ m/s^2$ /AD

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

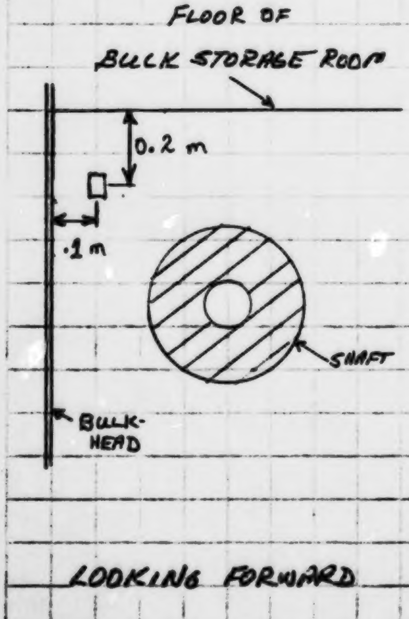
JOB. NO. 2452C
PROJECT M.V KALVIK PROPULSION
SUBJECT ACCELEROMETER LOCATIONS
SHEET 1 OF 1
DATE AUG 2E,
BY AL
CH'K. BY

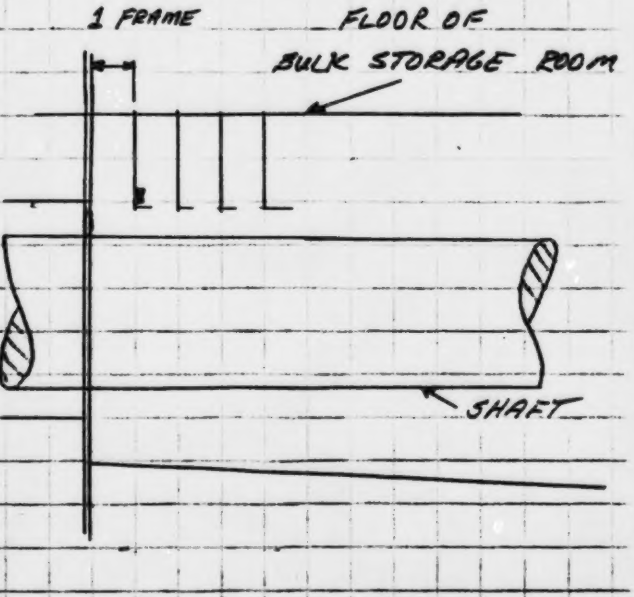
PORT SIDE ACV 34P





STARBOARD SIDE ACV 34S

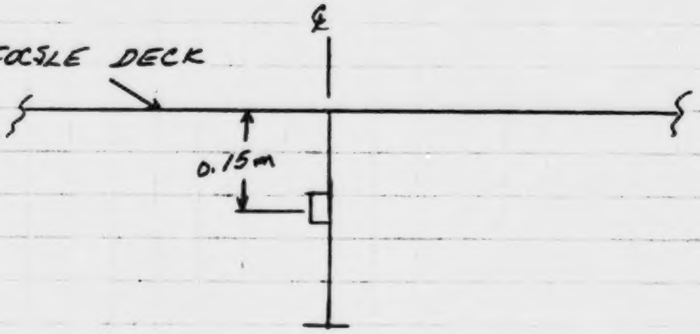




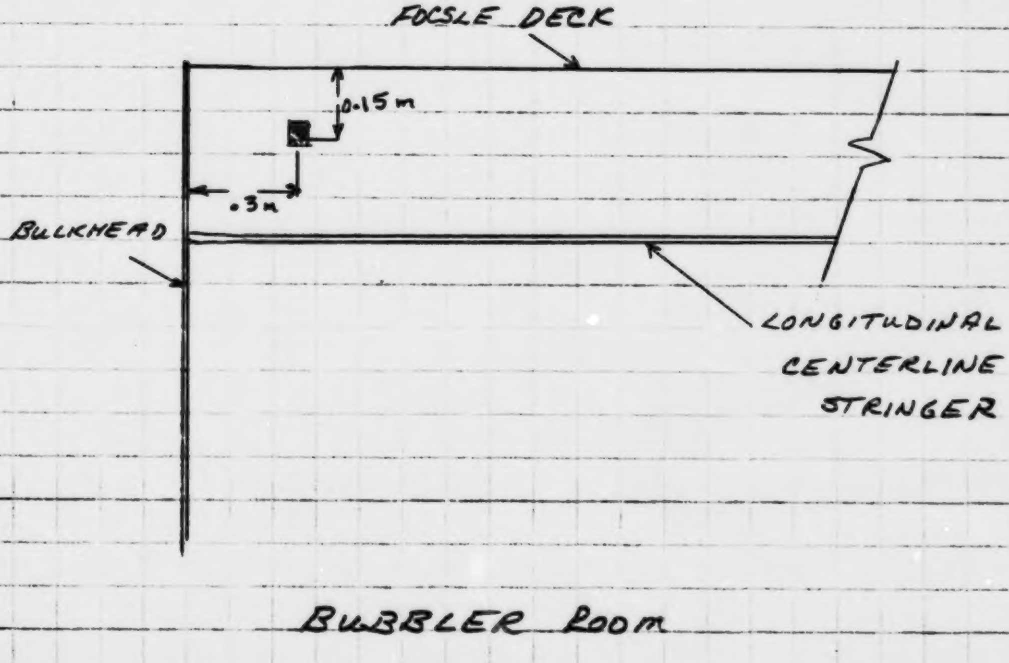
ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452C
PROJECT MV KALVIK
SUBJECT LOCATION OF FORWARD ACCELEROMETER
SHEET .... OF ....
DATE Aug 28/
BY Al
CH'K. BY ....

ACVF.



LOOKING FWD



BUBBLER ROOM

← FORWARD

ARCTEC CANADA LIMITED

ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452

PROJECT

SUBJECT Accelerometer Calibration

SHEET 1 OF 2

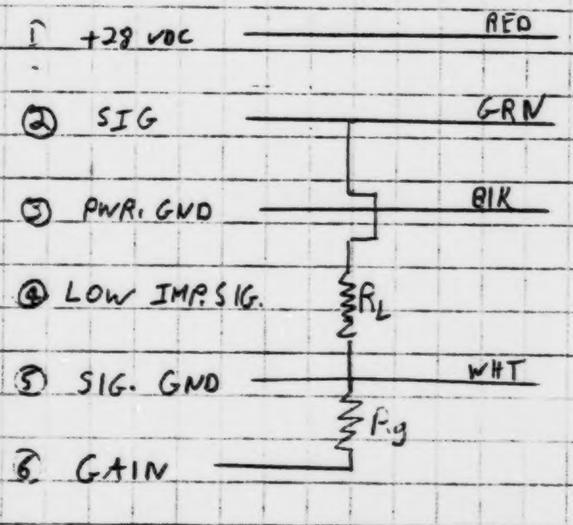
DATE Aug 30/86

BY PB/ME

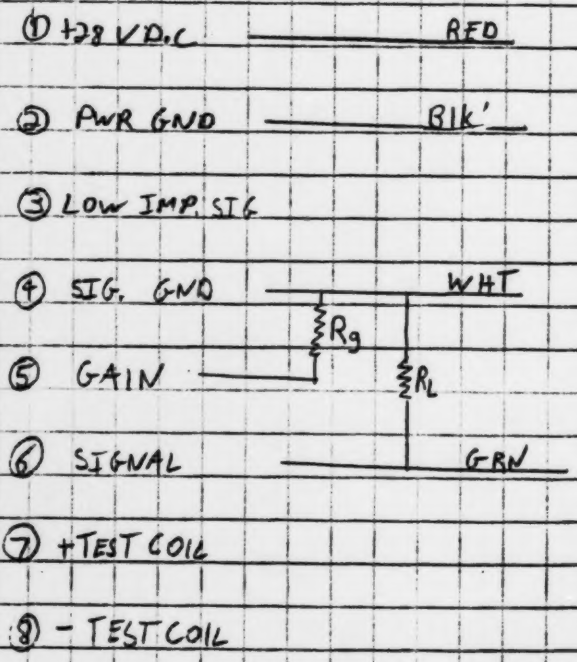
CH'K. BY

Serial No	Model Number	Rg	RL	Vmax	Vmin	ID
5557	303814	39K	4.7K	+1.026	-1.286	ACV34 S
3587	303T102	19.44K	4.61K	+0.757	-1.010	ACVF
3682	303T102	26.9k	4.61K	+1.036	-.809	ACV34P

Model 303B14



Model 303T102



ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452C
PROJECT MV KALVIK PROPULSION
SUBJECT SPEED CALIBRATION

SHEET .... OF .....
DATE FEB 18,
BY AL
CH'K. BY ....

COMPONENT	CALIBRATION FACTOR
DOPPLER SPEED LOG	29.3 mph/VOLT

THE SPEED WAS RECORDED USING A MICROWAVE SPEED LOG POSITIONED AT THE FORWARD END OF THE SHIP. THE CALIBRATION WAS CONDUCTED USING THREE DIFFERENT CALIBRATED TUNING FORK

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT M.V. KALVIK.
SUBJECT DOPPLER SPEED LOG CH. 13
SHEET .... OF ......
DATE 26/09/81
BY D.H.B.L.
CH'K. BY ....

SPEED	VOLTS	mph/VOLT
30 mph	1.029	29.15
40 mph	2.65	29.27
17.4 mph	0.59	29.49

AVG. mph/VOLT = 29.3 mph/VOLT

1 mph = 1.61 km/hr = 0.447 m/sec

CALIB (SPEED) = (0.447)(29.3)(.005) = 0.0655
(m/s)/(mph) (mph/VOLT) (VOLT/ADCOUNT)

CALIB (SPEE) = 0.0655 [m/sec / AD COUNT

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452C
PROJECT M.V. KALVIK PROPULSION
SUBJECT PROXIMETY PROBES

SHEET .... OF ....
DATE FEB 18,
BY
CH'K. BY

COMPONENT	CALIBRATION FACTOR
PROX F1	50 mv/mil
PROX F2	50 mv/mil
ANG POS	1 pulse/REV

THE MANUFACTURERS CALIBRATION FACTOR WAS USED FOR ALL OF THE PROXIMETY PROBE. THE POSITION OF THE SHAFT WAS MONITORED USING A PROBE WHICH GAVE A PULSE SIGNAL WHENEVER THE PROPELLER SHAFT REACHED T.D.C.. THE LOCATION OF EACH OF THE PROBES IS IN THIS SECTION.

THE RPM OF THE SHIPS PROPELLER SHAFT WAS ALSO MONITORED USING THE ANGULAR POSITION PROXIMETY PROBE.

JOB. NO.
PROJECT
SUBJECT Calibration check of Prox. Prob.

SHEET ... OF ...
DATE Feb. 13
BY Ron Ritch
CH'K. BY

Manufacture =? mV/mil

Attenuation of 2 ∴ 25 mV/mil

$$\frac{1}{25}\ \text{mil}/\text{mV} \times \frac{1\ \text{in}}{1000\ \text{mil}} = 4\times10^{-5}\ \text{in}/\text{mV}$$

$$4\times10^{-5}\ \text{in}/\text{mV} \times \frac{25.4\,\text{mm}}{\text{in}} = 1.016\times10^{-3}\ \text{mm}/\text{mV}$$

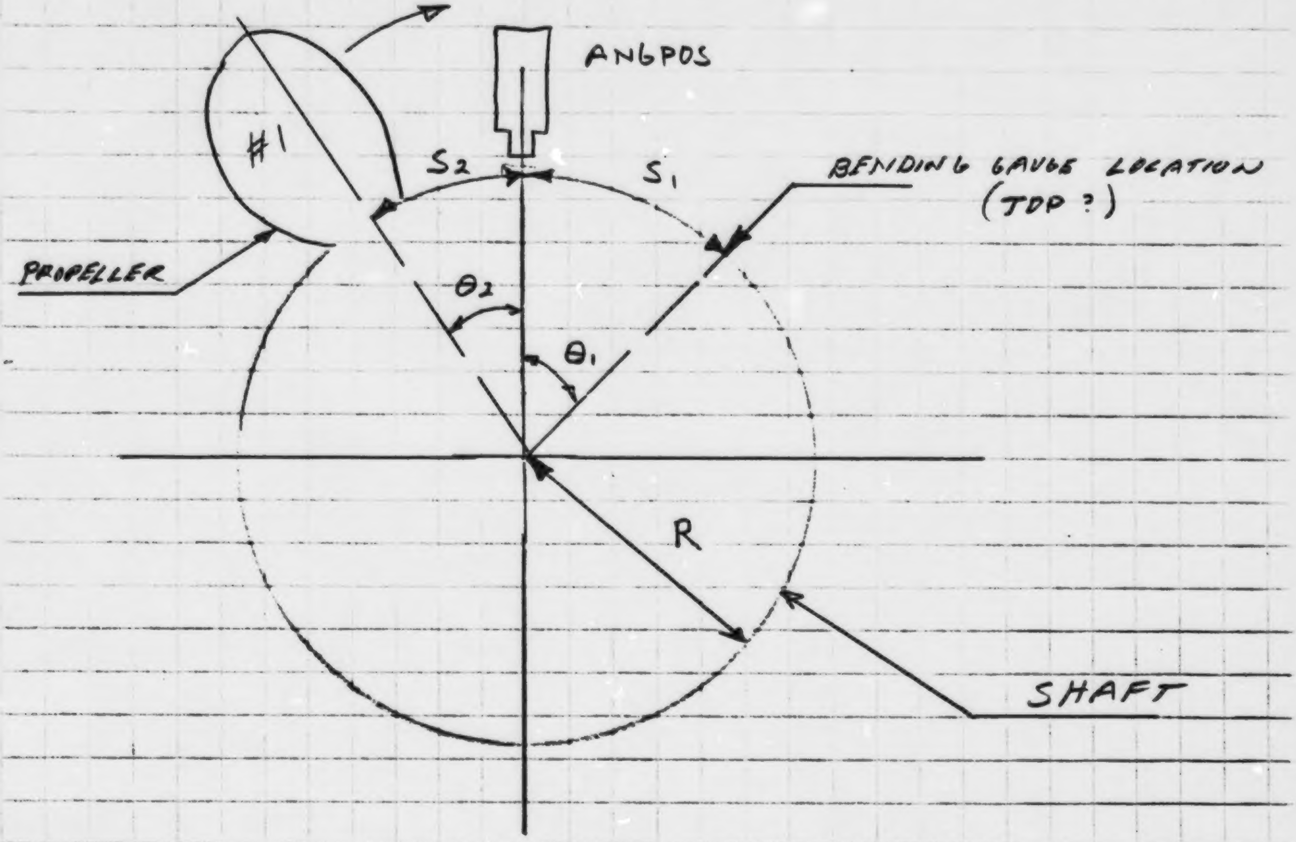
$$1.016\times10^{3}\ \frac{\text{mm}}{\text{mV}} \times \frac{1000\ \text{mV}}{1\ \text{V}} = 1.016\ \text{mm}/\text{V}$$

$$1.016\ \text{mm}/\text{V} \times \frac{.005\,\text{V}}{\text{AD}} = 0.00508\ \text{mm}/\text{AD}$$

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT
SUBJECT
ANG. POS LOCATION

SHEET .... OF ....
DATE 86/08/29
BY DNBL
CH'K. BY



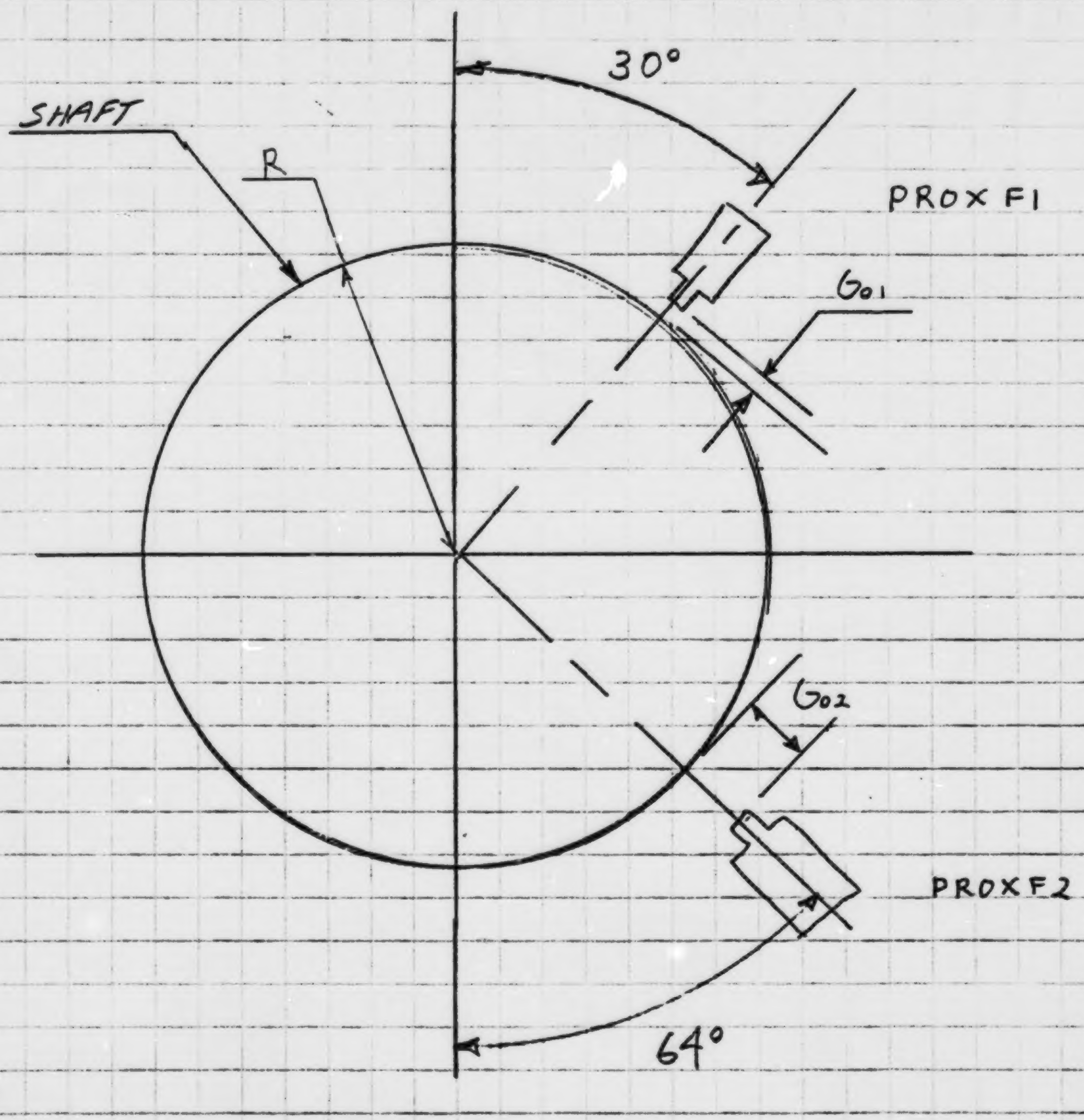
LOOKING FWD

GAUGE I.D.	S_1/S_2	R	θ_1/θ_2
SB 36	7 1/8"		
SB 99	6 1/4"		
PROPELLER	8 1/2"		

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT M.V. KALVIK
SUBJECT PROX. PROBE LOCATIONS: FWD.

SHEET .... OF ....
DATE 84/08/23
BY DNBL
CH'K. BY ....



LOOKING AFT

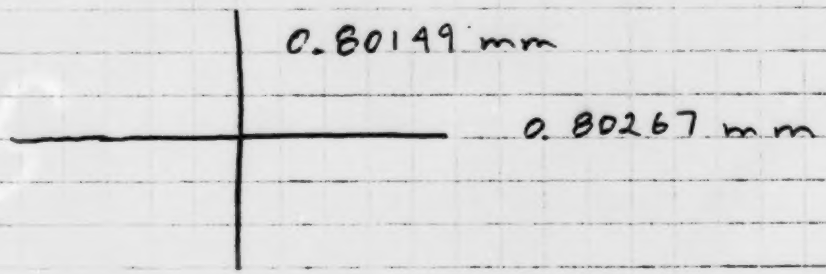
G_{01} = 4.15 mm (−10.11 VOLTS)/2 = 5.1
G_{02} = 4.5 mm (−11.02 VOLTS)/2 = 5.5
R = 800.0 mm

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT
SUBJECT

SHEET ... OF ...
DATE 87/02/1
BY
CH'K. BY

- FWD. STERN TUBE BEARING - FWD - "MIC'S"



SHAFT DIA. = $800.1^{\pm 0.1}$ mm.

VERTICAL CLEARANCE = 2.1 mm DIAM.
HORIZONTAL CLEARANCE = 2.4 mm DIAM.
AVG = 2.25

LIPS SEAL CLEARANCE MAX - 5.5 mm DIA.

LEAKAGE > 2mm RADIAL MOVEMENT

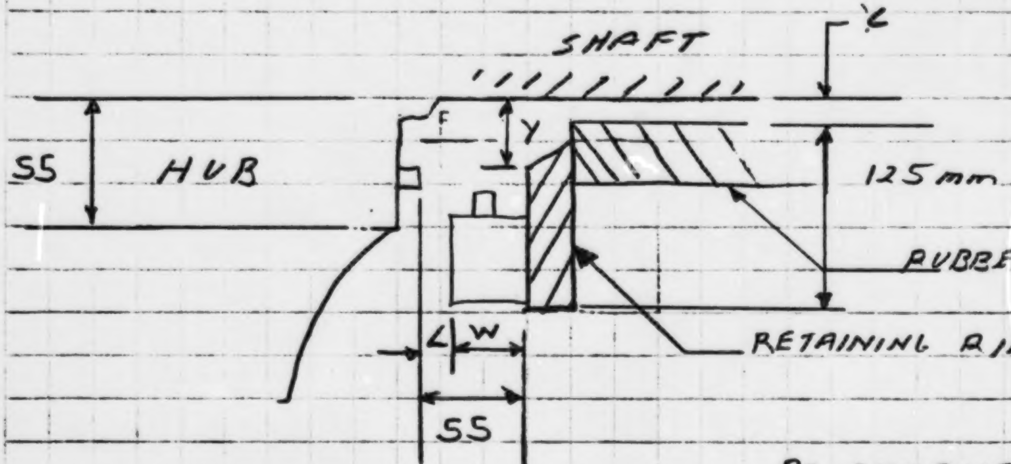
ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2452
PROJECT M.V. KALVIK
SUBJECT PROXIMITY PROBE INSTALLATION.

SHEET 1 OF 4
DATE 86/08/12
BY AHBC/R.R.
CH'K. BY

PROBE RANGE = 60 - 280 mil.
(1.5 - 7.1 mm)

MEASUREMENTS ON SITE



ELEVATION VIEW

P = DISTANCE FROM PROBE TIP TO SHAFT = ?
W = TOTAL PROBE + BRKT. WIDTH

TOP OF SHAFT Y ≐ 36 mm
BOTTOM OF SHAFT Y ≐ 27 mm
STBD. SIDE Y =
PORT SIDE Y =

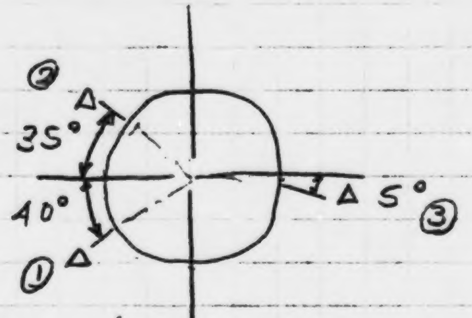
JOHNSON RUBBER: L = 90 mil ≐ 2.3 mm (T.B.)
(AT TOP OF SHAFT)

L ≐ 40 mil @ HORIZONTAL POSITION
(1 mm)

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. 2952
PROJECT M.V. KALVIK
SUBJECT PROXIMITY PROBE LOCATIONS
SHEET 2 OF 4
DATE 86/03/11.
BY D.N.B.C.
CH'K. BY

MAXIMUM (C) FOR PROBE POSITIONS : ?



AFT PROBE LOCATIONS
LOOKING FORWARD.

MAX C = 60 mil + (Dynamic Strain) = 60 + (Dε,

MAX DYNAMIC LOAD = 3× STATIC = 120 p.s.i.

E_{RUBBER} ≐ 6000 psi.

Dε = 120/6000 = 12/600 = 1/50 = 0.02

Dε = (20,000 με)(1.75) = 0.035" = 35 mil ←

MAX c ≐ 60 + 35 = 95 mil = 2.4 mm ←

MAXIMUM RUBBER WEAR DOWN ~ 3mm

MAXIMUM SHAFT MOVEMENT RANGE = SR

SR = 60 + 35 + 35 = 130 mil

PROBE RANGE = 60 - 280 mil

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO. ....
PROJECT ....
SUBJECT ....

SHEET 3 OF 5
DATE 16/8/86
BY VL
CH'K. BY VL

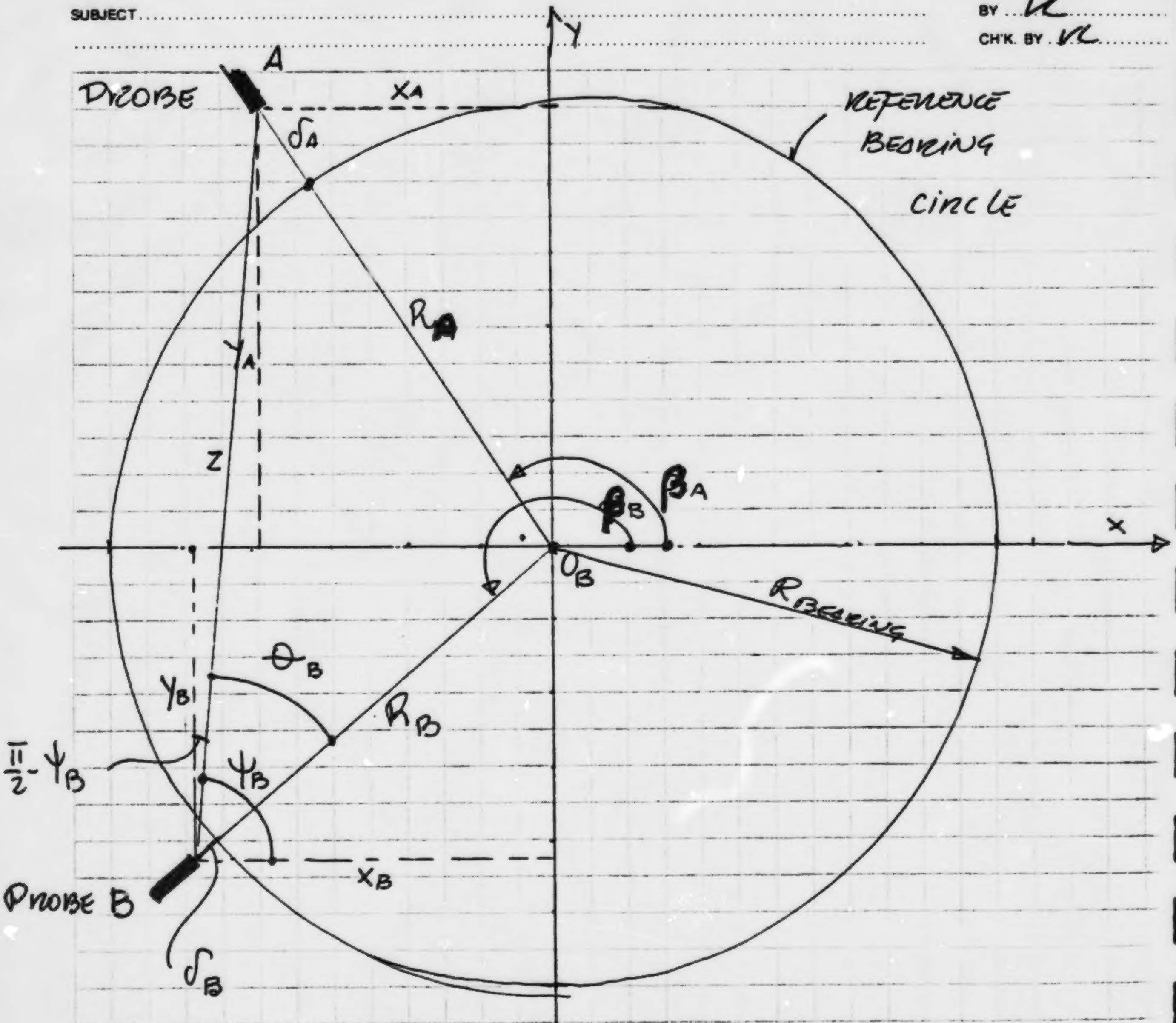


FIGURE 1

GEOMETRY OF PROBE LOCATIONS.

$$\tan \psi_B = \frac{y_A - y_B}{x_A - x_B}$$

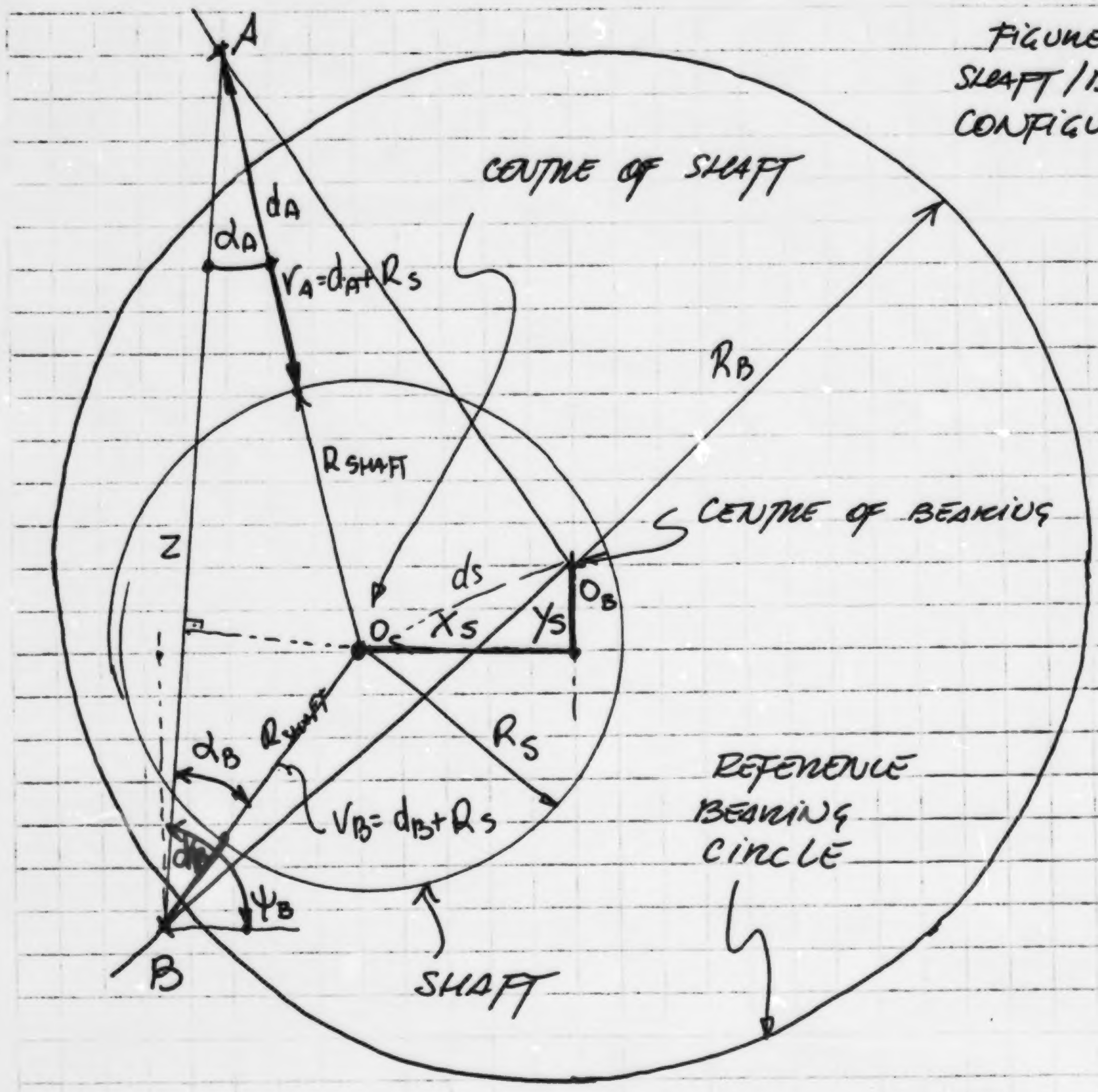
$$Z = \left((x_A - x_B)^2 + (y_A - y_B)^2 \right)^{1/2}$$

ARCTEC CANADA LIMITED
ENGINEERING DESIGN CALCULATIONS

JOB. NO.
PROJECT
SUBJECT

SHEET 4 OF 5
DATE 16/8/86
BY VL
CH'K. BY VL

FIGURE 2
SHAFT / BEARING CONFIGURATION



$$\left.\begin{aligned} V_A \sin\alpha_A &= V_B \sin\alpha_B \\ V_A \cos\alpha_A + V_B \cos\alpha_B &= Z \end{aligned}\right\} \text{ UNKNOWN } \alpha_A, \alpha_B$$

$V_A = d_A + R_S$
$V_B = d_B + R_S$

Z - DISTANCE BTWN PROBES A +
d_A - READING OF PROBE A
d_B - READING OF PROBE B
d_C - READING OF PROBE C
R_S - SHAFT RADIUS

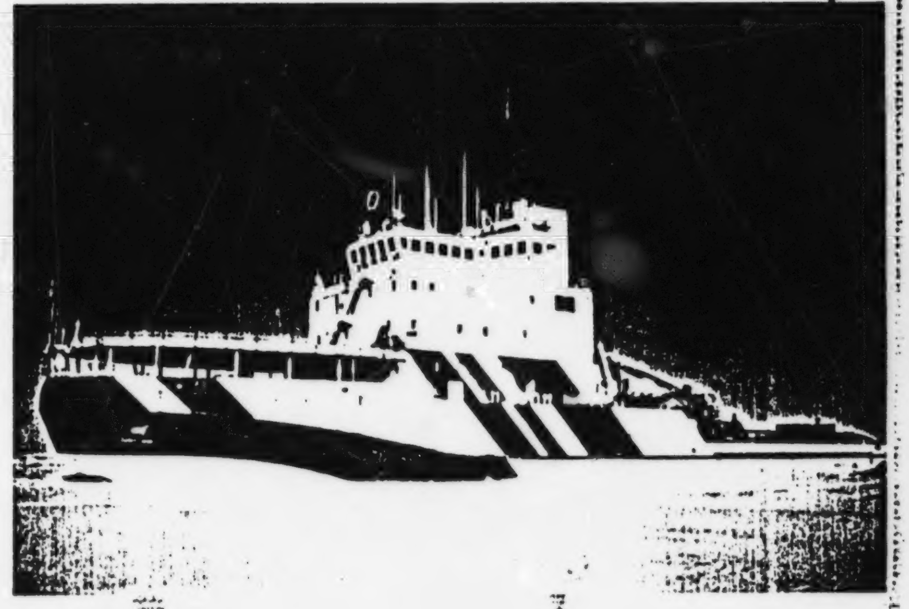
APPENDIX E

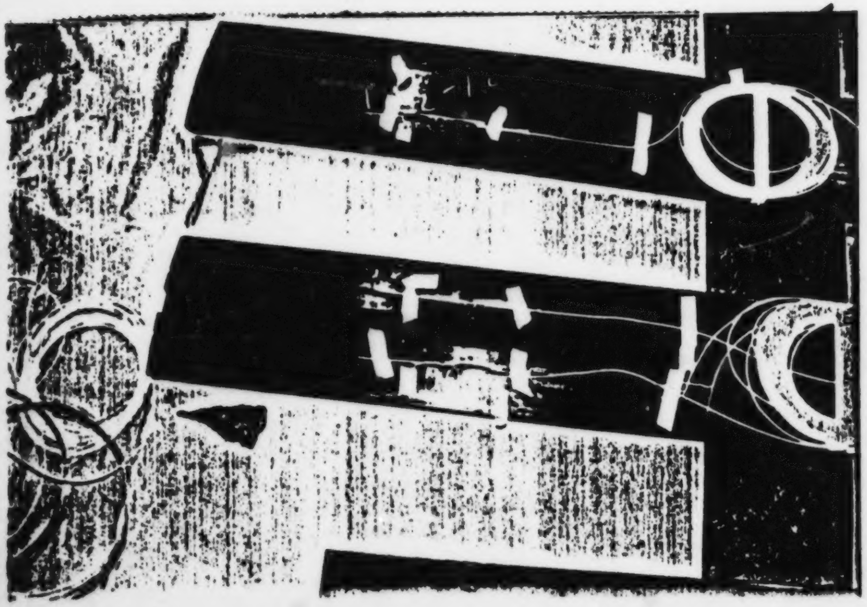
Photographs

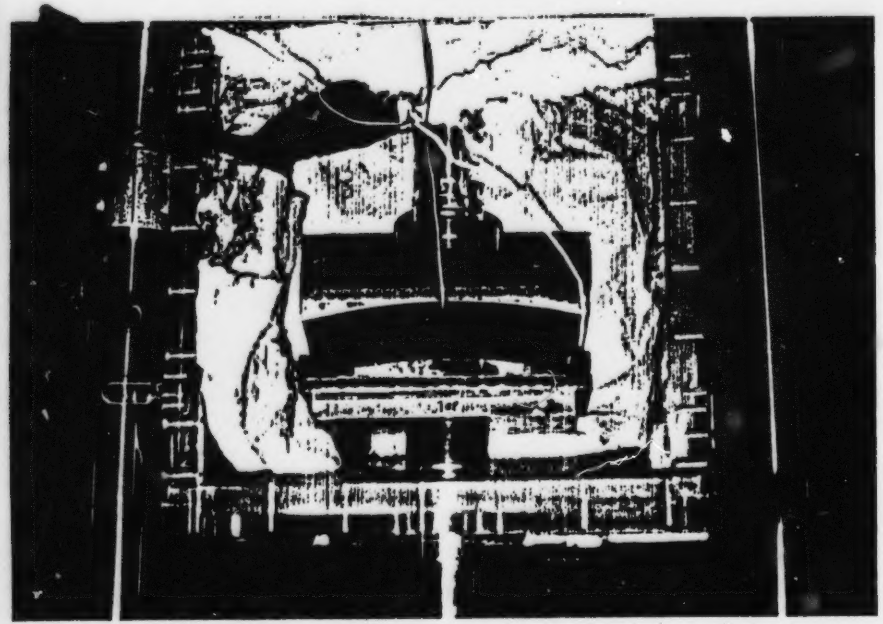
M.V. KALVIK PROPULSION SYSTEM FULL SCALE TEST

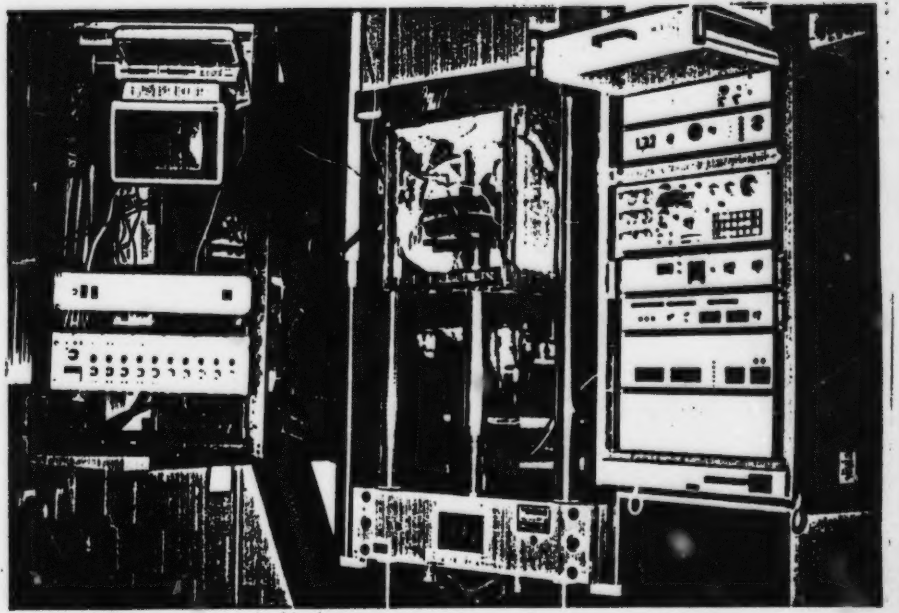
PHOTOGRAPHIC DOCUMENTATION

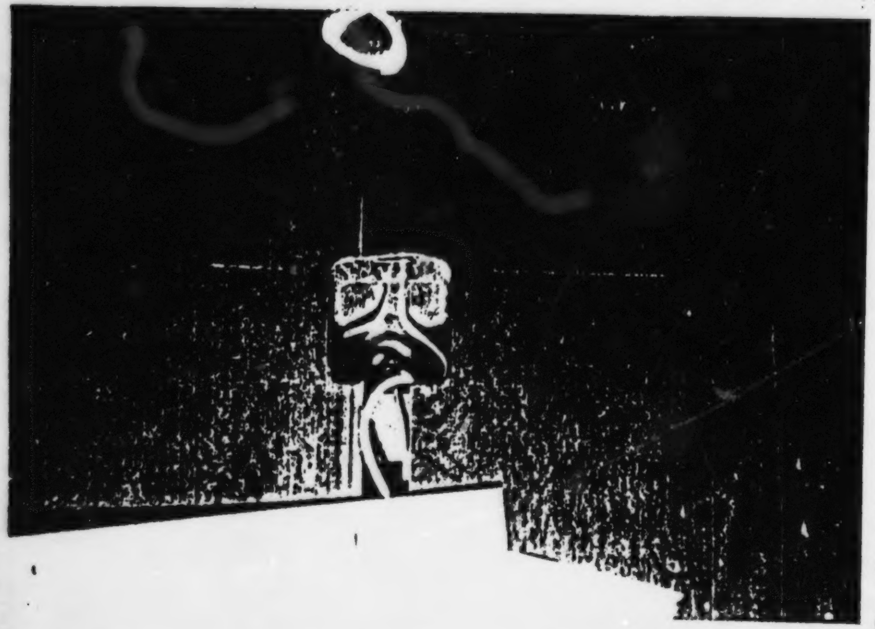
PICTURE	DESCRIPTION
1	M.V. Kalvik - New Hull Paint - Performance Tests
2	Installation of Rubber Bearing - Johnson Rubber Plant *(Picture removed at the request of The Johnson Rubber Company)*
3	Instrumented Rubber Staves - Johnson Rubber Plant
4	Instrumented Rubber Staves - Johnson Rubber Plant
5	Strain Gauge in Backside of Rubber Stave
6	Testing Mold and Section of Rubber Bearing
7	Compression Testing of Rubber Bearing
8	Test Facility Used on Rubber Bearing
9	Water-Proof Test of Strain Sensors in Bearing Material
10	Aft End of M.V. Kalvik in Drydock - Old Paint
11	Starboard Propeller - Old Blades
12	Starboard Propeller Shaft - Drydock
13	Starboard Stern Tube
14	Removing Old Staves Looking Forward from Aft End
15	Old Rubber Staves
16	Damaged Blades from Starboard Propeller
17	Holes Drilled in Retaining Ring - Aft Stern Tube Bearing
18	Fwd. End of Aft Stern Tube Bushing - Looking Fwd.
19	Installation of Instrumented Staves - Aft Bearing
20	Aft Stern Tube Bearing - New Bearings
21	Channel Welded to Top of Stern Tube Bearing
22	Penetration of Stern Tube - Wires and Water Tight Gland
23	Insitu Calibration Tests of Instrumented Bearings
24	Calibration of Intermediate Bearing
25	Starboard Shaft Tunnel
26	Starboard Shaft- Instrumentation for Thrust, Bending R.P.M.
27	Starboard Aft End - New Blades
28	Fwd. End of M.V. Kalvik in Drydock - New Paint
29	Block of Ice that was Stuck in Propeller
30	Vast Ice Floe During Performance Tests
31	Milled Ice Piece
32	Milled Ice
33	Ice off Starboard Aft. End - Stbd. Prop. Stuck
34	Ice Testing Crew
35	Helicopter and Ice Testing Personnel
36	Ice Testing Crew
37	Captain's Maneuver - M.V. Kalvik
38	M.V.Kalvik - Backing in Level Ice
39	Bow Print from Ramming Multi-year Ice Ridge
40	C.G.C.S. John A. MacDonald and M.V. Kalvik - Scenery

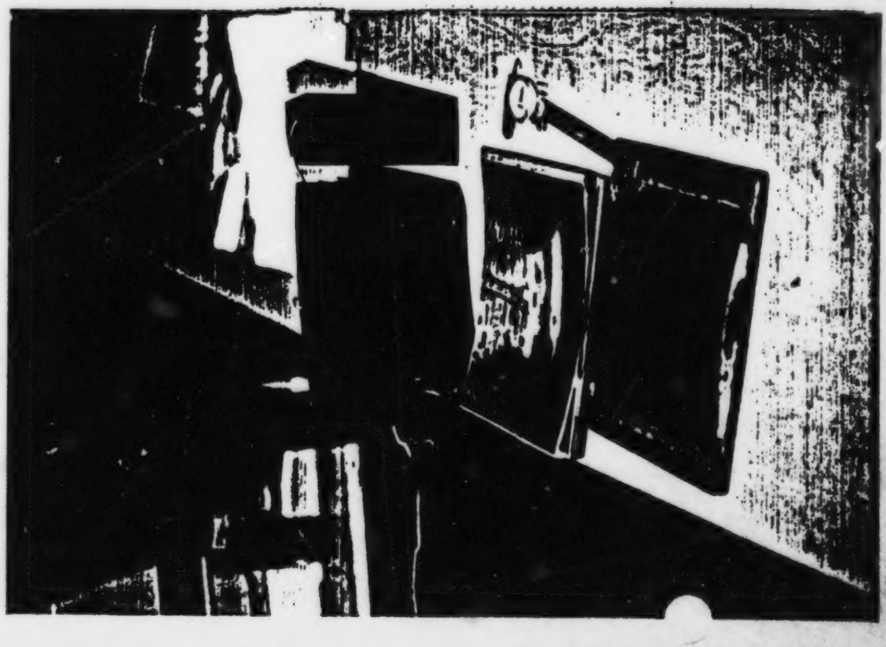


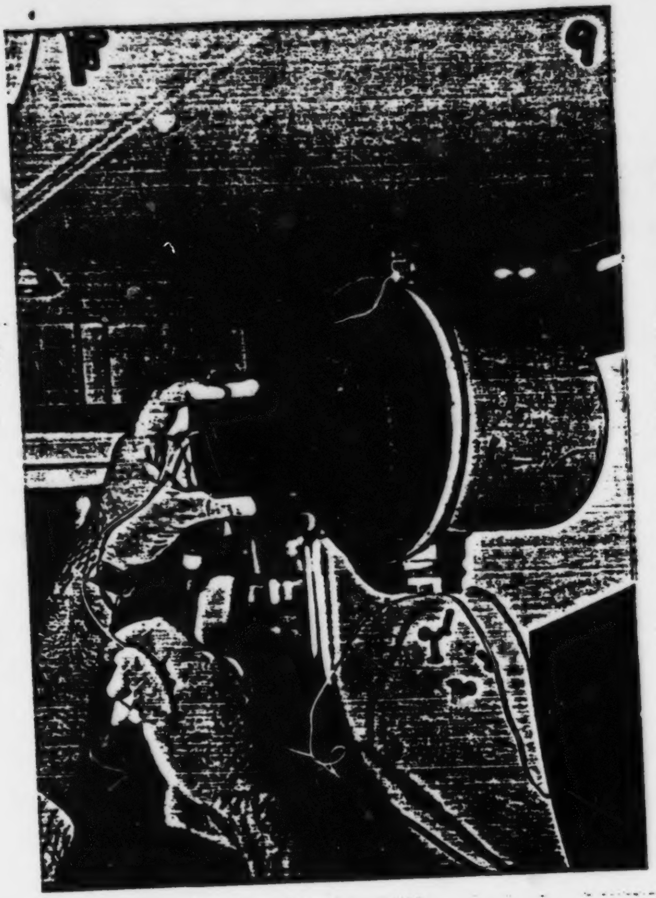








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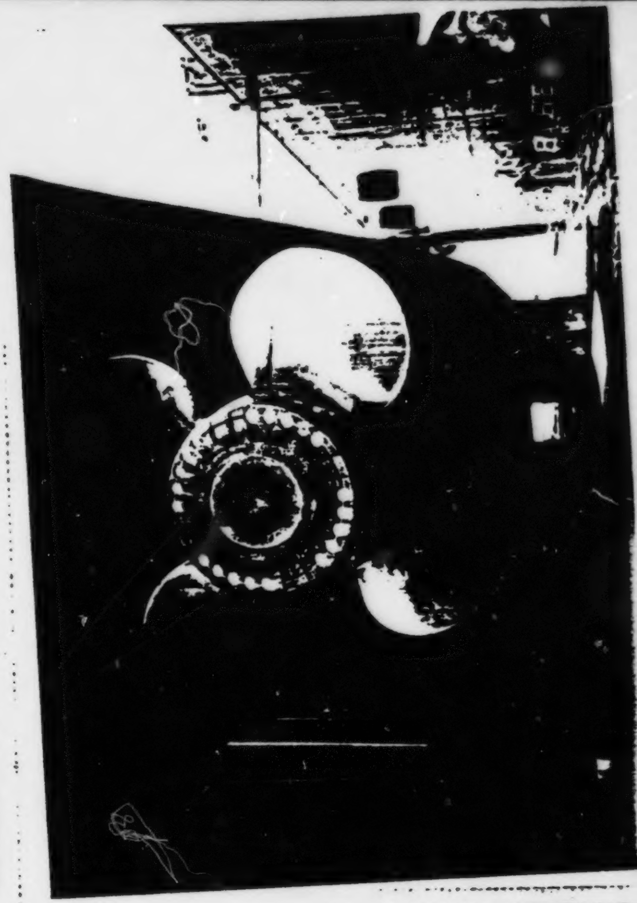

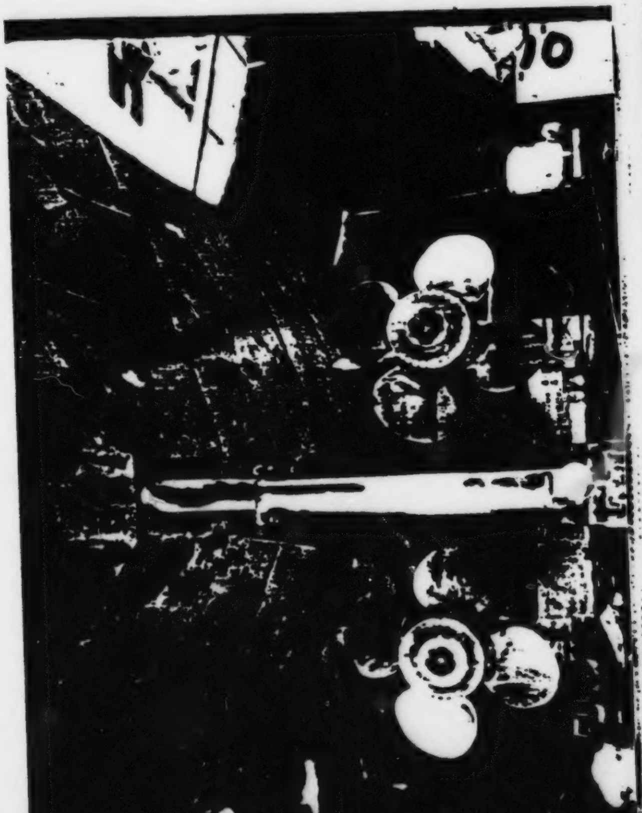
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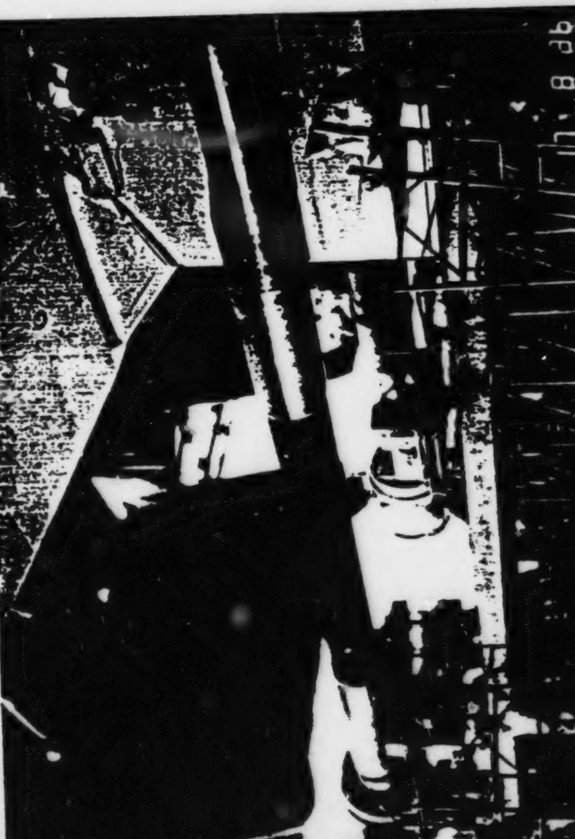

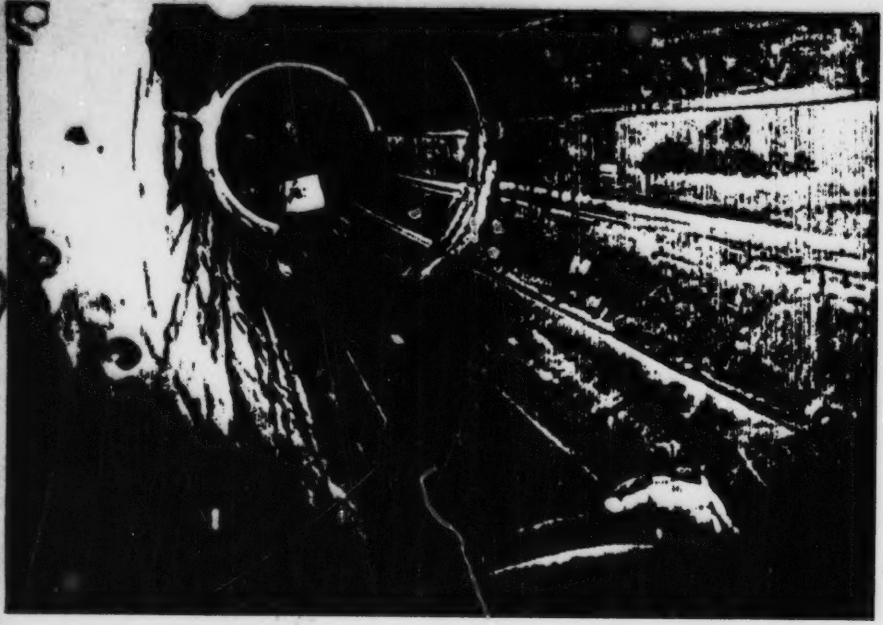

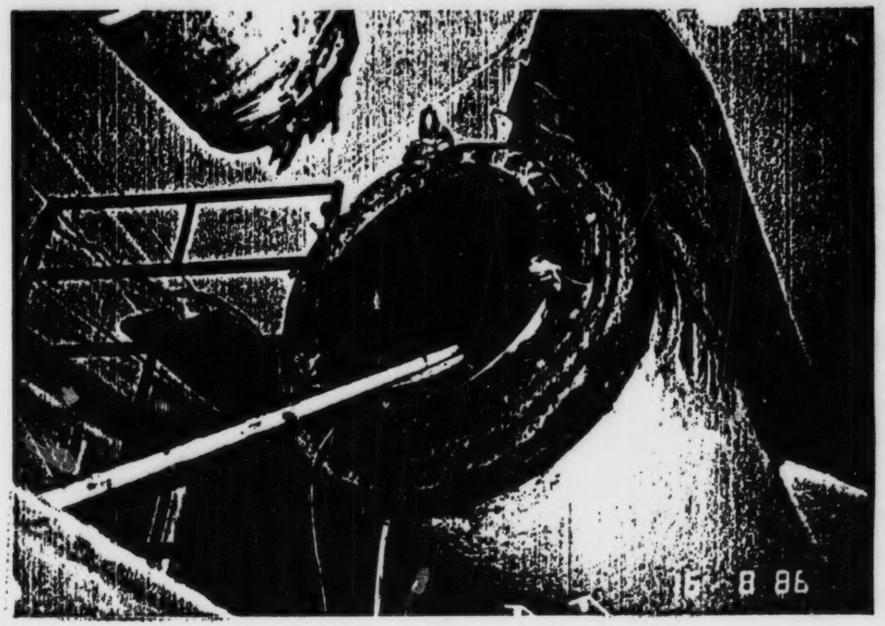
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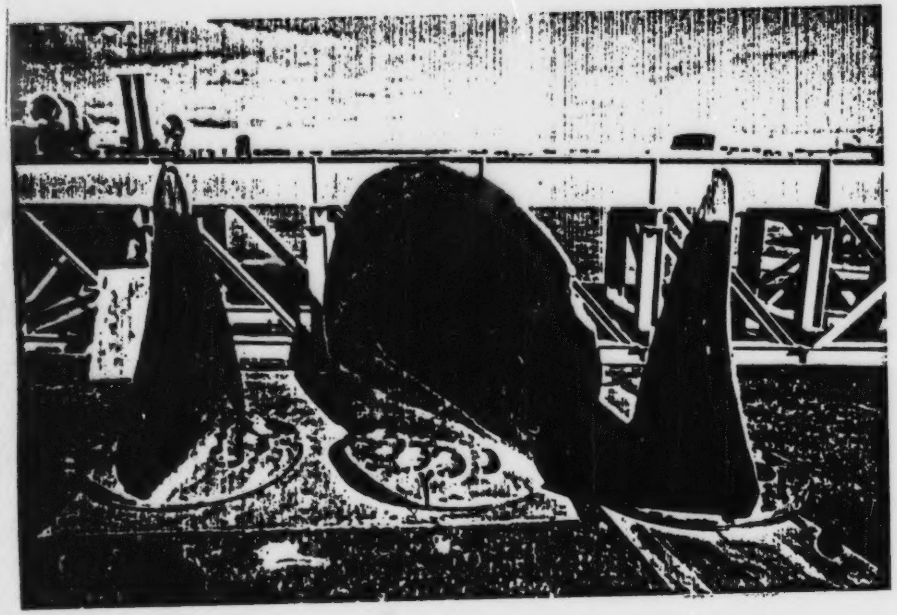

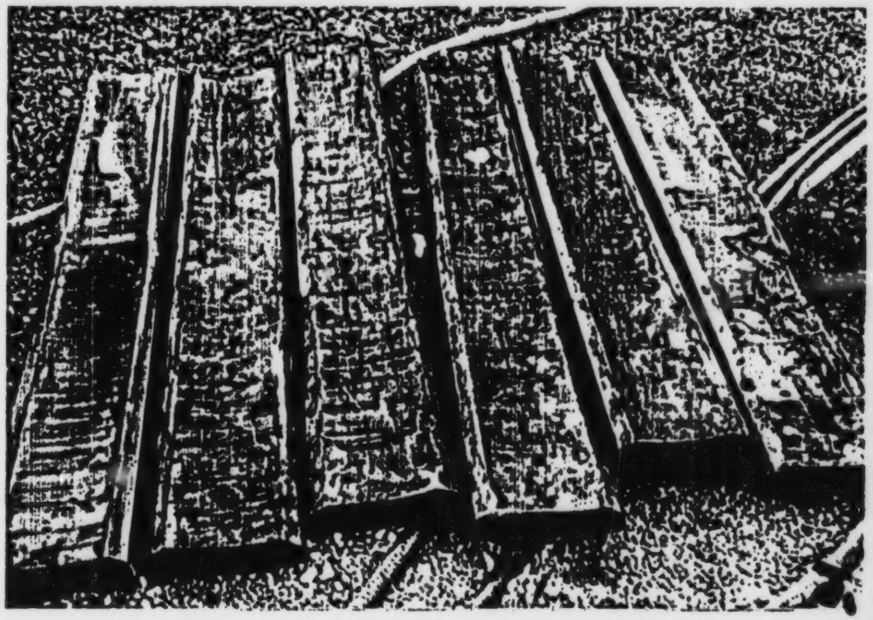

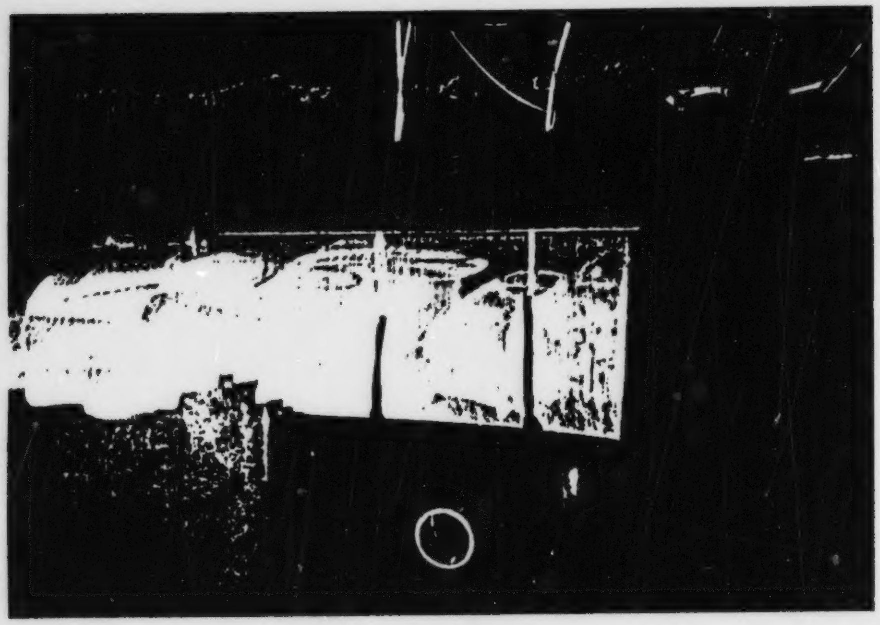

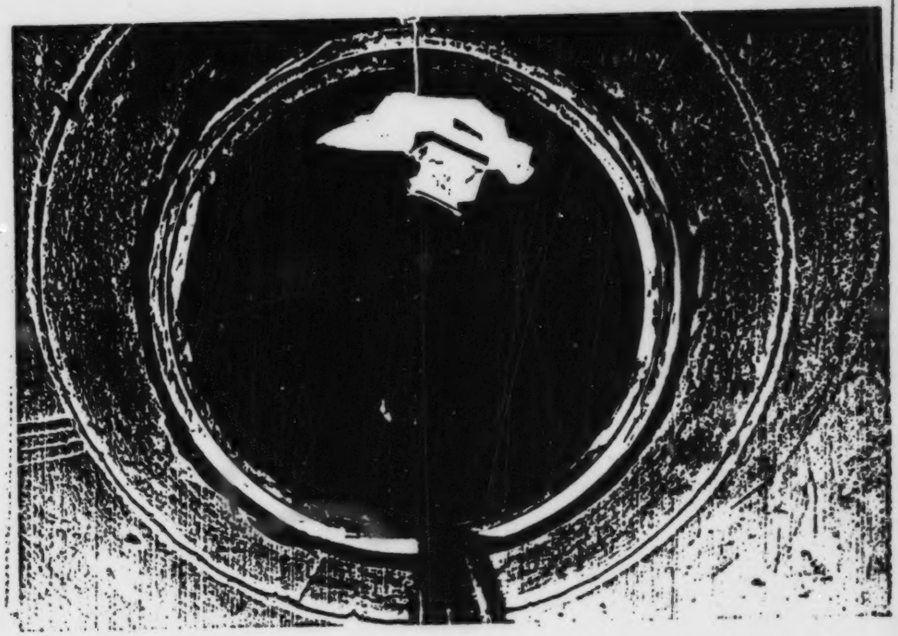

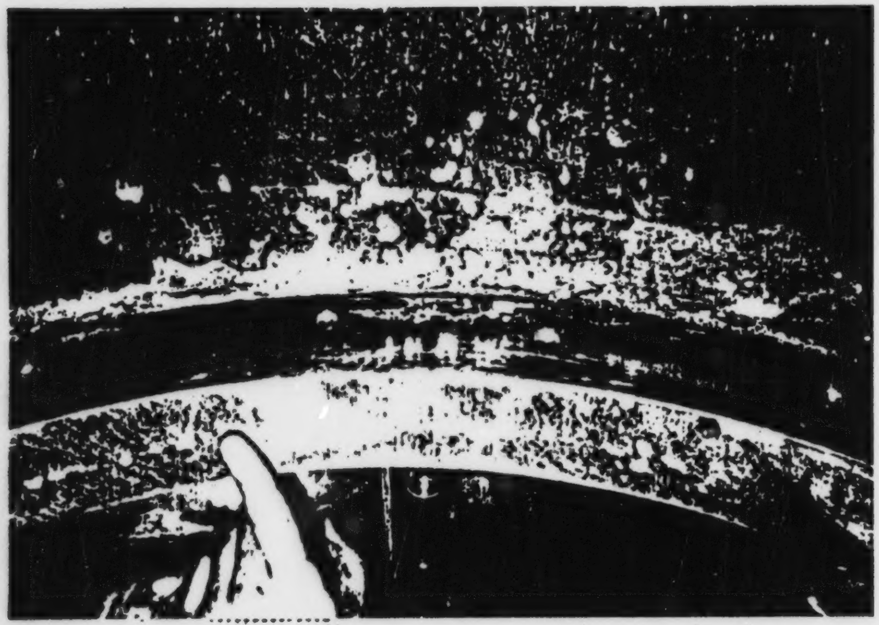

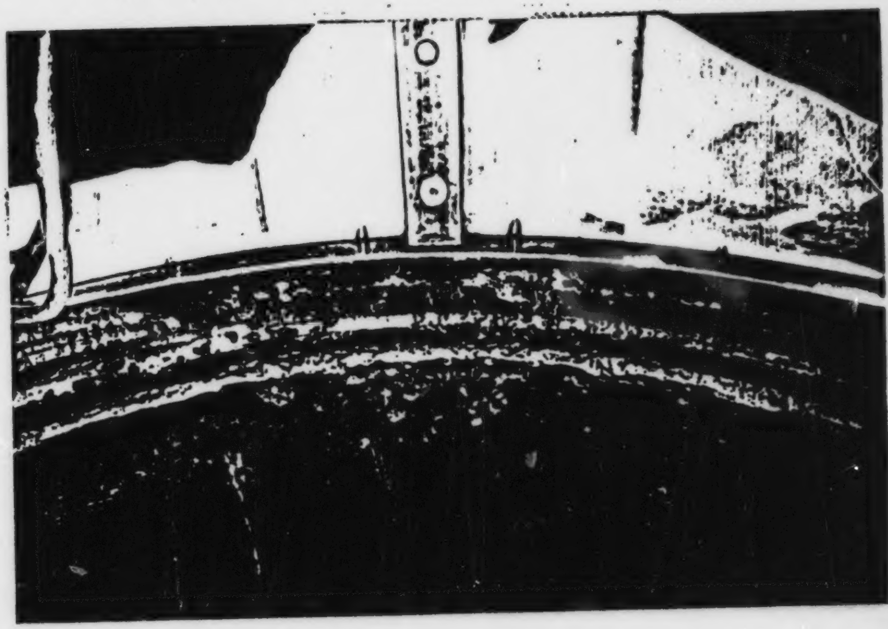

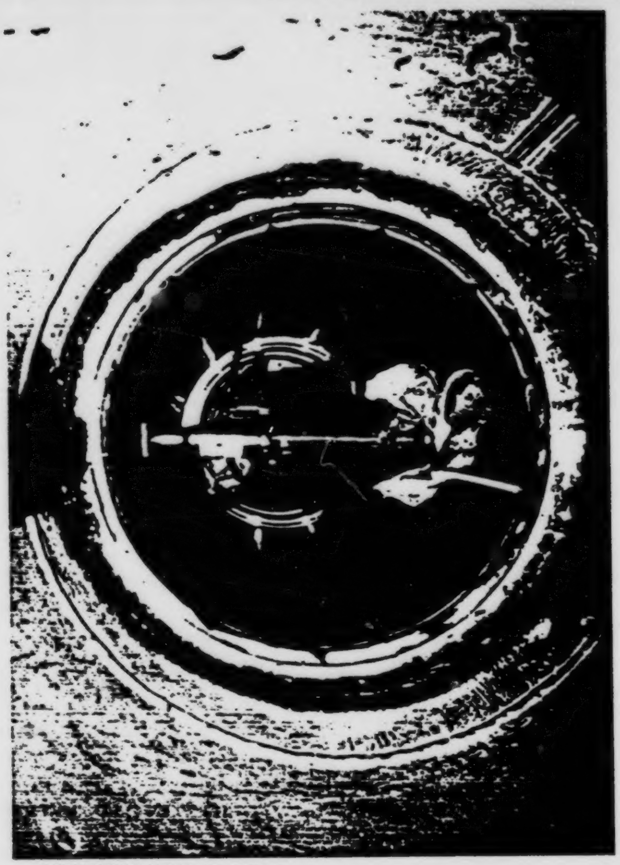

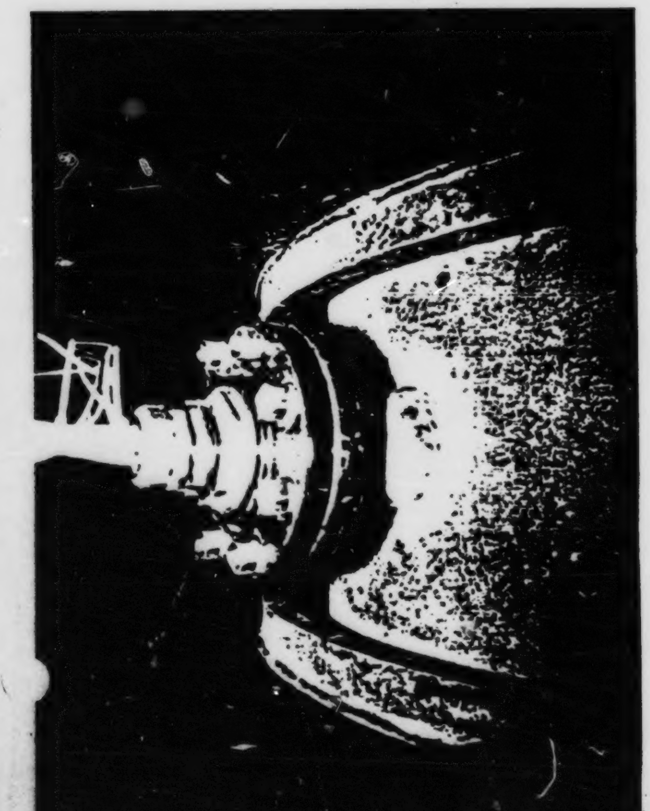

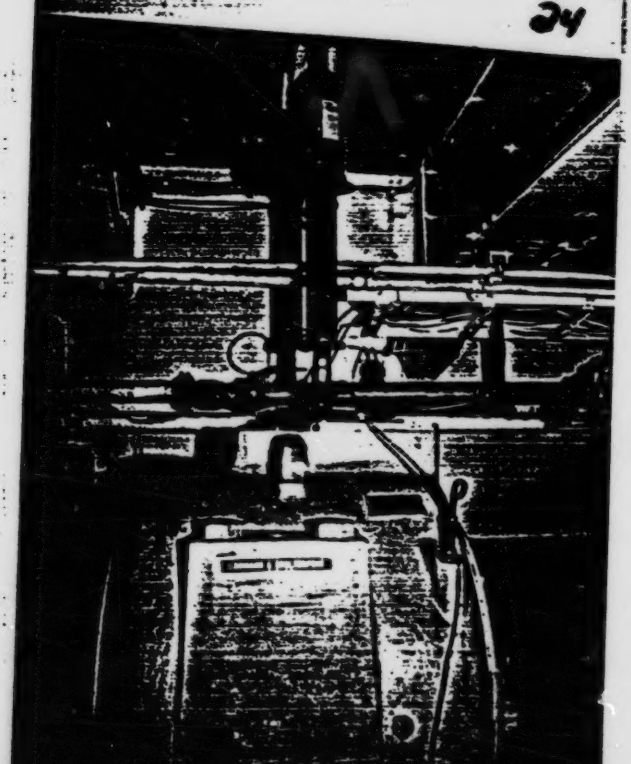

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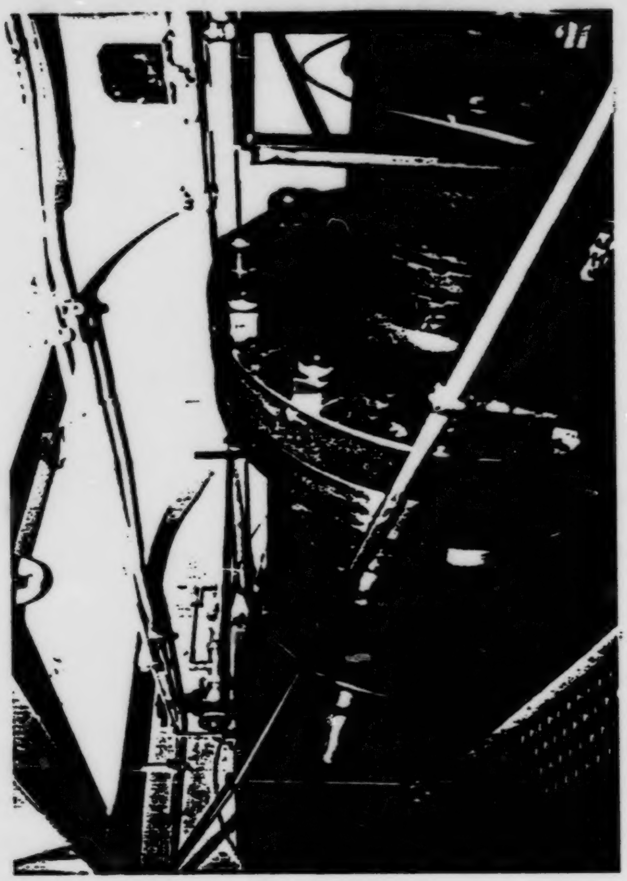

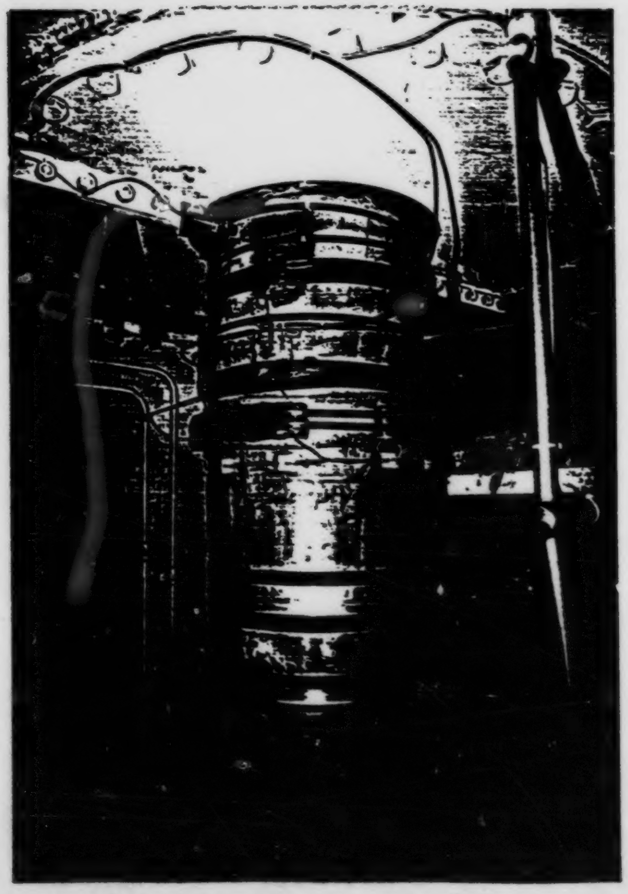
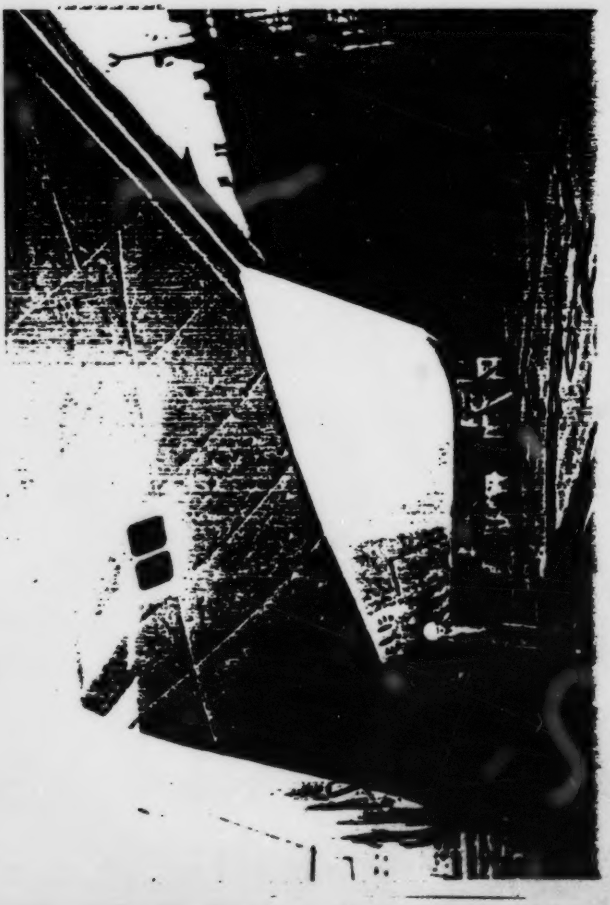

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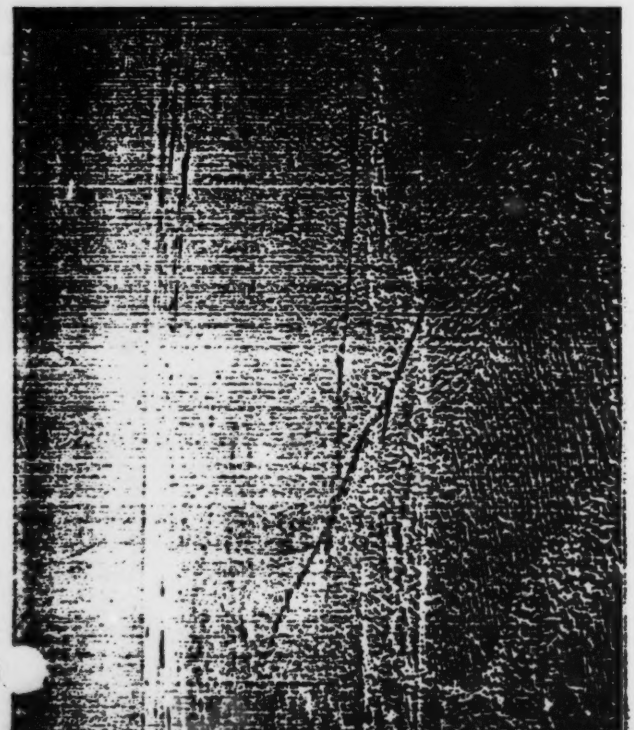

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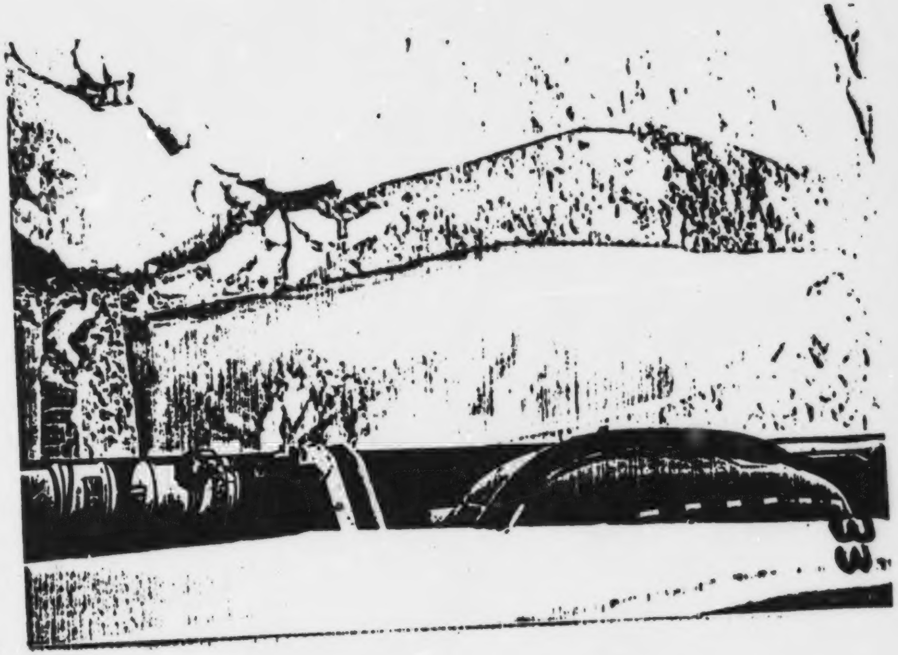
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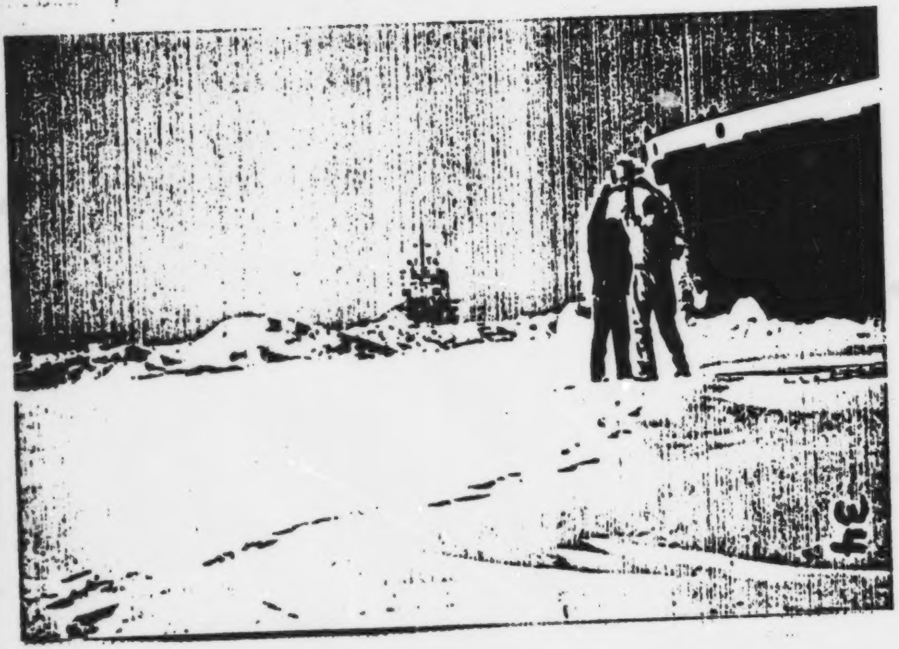
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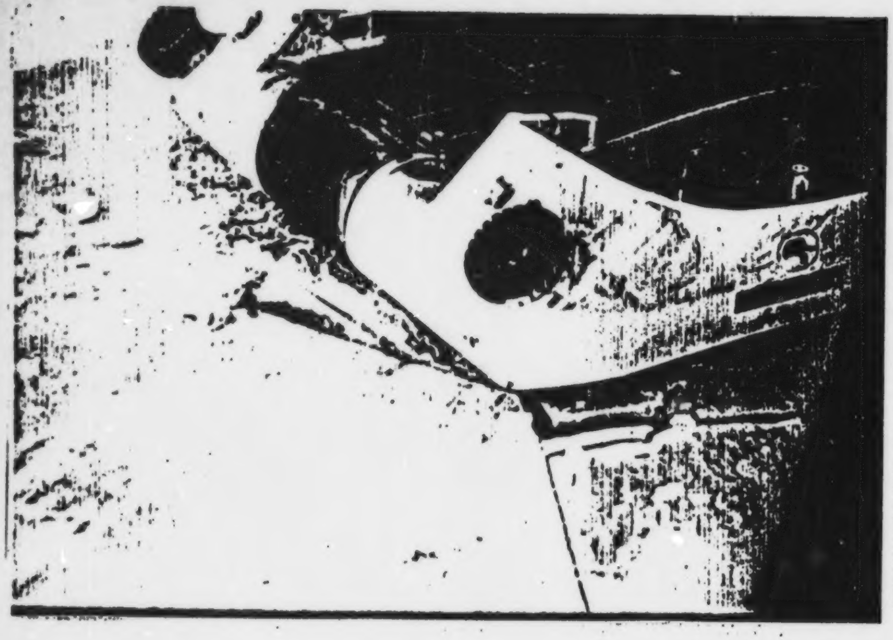

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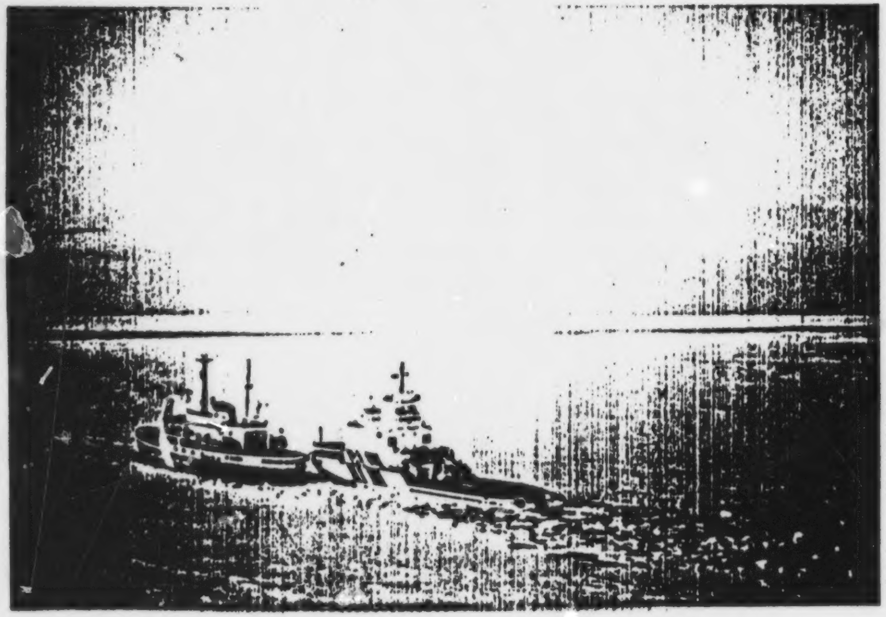

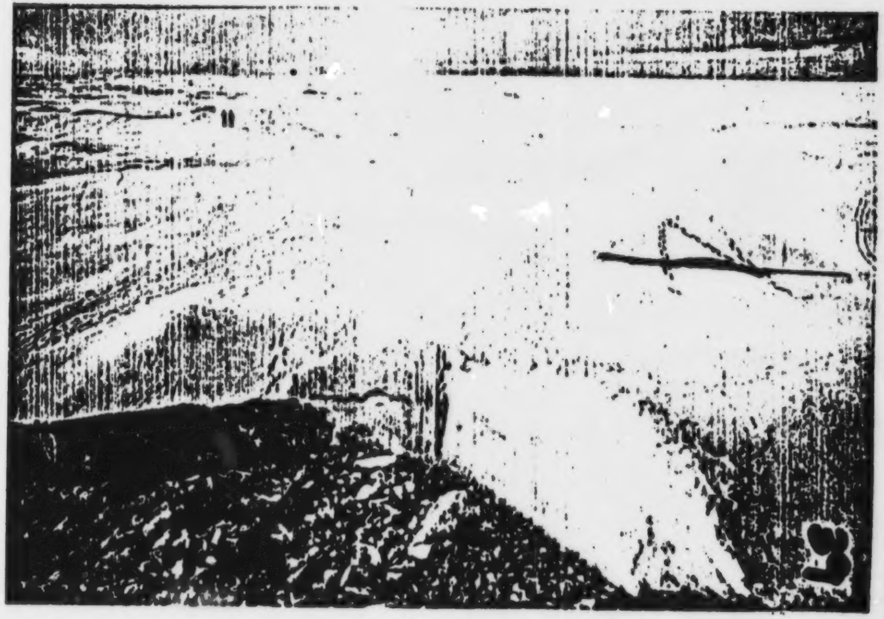
37

APPENDIX F

Software Listing

```
1     !=============================================
2     ! PROGRAM 'DA_2452_F'
3     !=============================================
4     !
5     !
6     ! USED FOR THE 1985 M.V. KALVIK PROPULSION SYSTEM FULL SCALE TESTS
7     !
8     ! ARCTEC CANADA LIMITED  MARCH 25,1987
9     !
10    OPTION BASE 1
11    DEG
12    PRINTER IS 1
13    !
14    !
15    !
16    !
17    !  All the "Names" of your I/O Functions
18    !  must be listed in the COMmon called
19    !  /Names/ here.
20    !
21    COM /Names/ Buffer_m
22    COM /Names/ A_d,Scan_con
23    !
24    !
25    !
26    ! HARDWARE CONFIGURATION:
27    !
28    !    2- 1M BYTE MEMORY BOARD
29    !    1- HF9836 DESK TOP COMPUTER
30    !    1- INFOTEK AD200 CARD WITH CABLE
31    !    1- HP6942A MULTIPROGRAMMER
32    !    1- 500 KHZ A/D CARD
33    !
34    !    1- HP6922 HPIB INTERFACE
35    !
36    ! OPERATING SYSTEM CONFIGURATION
37    !
38    !    BASIC 3.0
39    !
40    !========================
41    ! VARIABLE DECLARATIONS
42    !=========================
43    !
44    ! REAL ARRAYS
45    !======================================================================
46    !
47    !====================================================================
48    ! INTEGER ARRAYS
49    !======================================================================
50    COM INTEGER Ad_d(2) BUFFER ! ARRAY FOR DATA TRANSFER AD200
51    !
52    COM INTEGER Data(3125,80) BUFFER       ! ARRAY FOR DATA TRANSFER HP6942A
53    ASSIGN @Buff_6942 TO BUFFER Data(*)
54    ASSIGN @Ad_buff TO BUFFER Ad_d(*)
55    !
56    COM INTEGER Cat_plot(18)  ! CHANNEL NUMBER FOR CATALOGUE PLOTS ROUTINE
57    COM INTEGER Filt_chn(80)  ! CHANNEL NUMBER TO FILTER
58    !
59    !
```

```
60    !==================================================
61    ! DECLARATIONS FOR STATISTICS CSUB
62    !==================================================
63    !
64    COM INTEGER Baseline(80),Alarm_lims(80)
65    !
66    COM INTEGER Alarm_flg,Nchns,Nchnls,Nscans,Buff
67    COM INTEGER Mnmxmean(3,80),Mnmxptrs(3,80),Alarm_type(80),Alarm_cnt(80)
68    COM REAL Max_mean(3,80)
69    !
70    !
71    ! INTEGERS
72    !============
73    INTEGER Position                         ! POSITION OF CURSOR
74    INTEGER Ad                               ! SELECT CODE OF AD200 CARD
75    COM INTEGER N_events                     ! NUMBER OF EVENTS
76    COM INTEGER I,J,K,M,L                    ! LOOP COUNTERS
77    COM INTEGER Pace_chn
78    !
79    !========================
80    !  REAL ARRAYS
81    !========================
82    !
83    REAL Over_l(80)                          ! OVER LIMIT OF CHANNEL
84    REAL Slope_l(80)                         ! MAXIMUM SLOPE OF TIME HISTORY
85    COM REAL Min_chn(100,80)                 ! MINIMUM VALUE OF CHANNELS
86    COM REAL Max_chn(100,80)                 ! MAXIMUM VALUE OF CHANNELS
87    COM REAL Mean_chn(100,80)                ! MEAN VALUE OF CHANNELS
88    COM REAL Mnx_c(2,80)                       ! MAXIMUM AND MINIMUM OF ALL EVENT
S
89    COM REAL Ev_max(2,80)                      ! EVENT NO OF MAX AND MIN
90    !
91    !
92    ! REAL VARIABLES
93    !================
94    COM REAL Pace,Array_sze                  ! PACE OF HP6942A
95    REAL Period                              ! PERIOD OF SCANNING AD200 CARD
96    REAL Nrdgs                               ! NUMBER OF READINGS
97    REAL Npts                                ! NUMBER OF READINGS/CHANNEL
98    REAL Xscale,Yscale                       ! SCALE VARIABLES FOR PLOTTING
99    COM REAL Time_acq
100   !
101   !================
102   ! STRING ARRAYS
103   !=================
104   DIM Unit_scale$(11)[1]        ! UNITS FOR PLOTTING
105   DIM Event_1$(30)[8]           ! EVENT LABELS FOR READING OFF TAPE
106   DIM D1$[7]                    ! DISK DRIVE TO STORE ON
107   DIM D0$[7]                    ! DISK DRIVE FOR PROGRAMS AND CONFIG FILES
108   DIM File$[8]                  ! FILE NAME FOR STORAGE
109   COM Event$[8]                 ! EVENT LABEL
110   DIM Figure$[80]               ! TITLE OF FIGURE
111   COM Catalog$(1:100)[80]       ! CATALOG OF DISK OR TAPE
112   !
113   !==================
114   ! STRING VARIABLES
115   !==================
116   DIM Unit_bend$[8]             ! UNITS OF BENDING GAUGES
117   DIM Title$[80]                ! TITLE OF GRAPH
118   DIM Title1$[80]                ! SECOND TITLE OF GRAPH
```

```
119   DIM Y_title$[50]                  ! Y AXIS TITLE
120   DIM X_title$[50]                  ! X AXIX TITLE
121   DIM X_unit$[8]                    ! X AXIS UNITS
122   DIM Y_unit$[8]                    ! Y AXIS UNITS
123   !
124   !=========================================================
125 Init_const:  !  INITIALIZE CONSTANTS DEFAULT CONSTANTS
126   !========================================================
127   !
128   Ad=17                            ! SELECT CODE OF A/D CONVERTER CARD
129   Nchns_ad=2                       ! NUMBER OF CHANNELS TO SCAN ON AD200 CARD
130   Npts_ad=1                        ! NUMBER OF POINTS/CHNS
131   !
132   Period=20000                     ! PERIOD IN Nano seconds(__ READINGS/SEC)
133   Period_$=VAL$(Period)            ! STRING CHARACTER OF PERIOD
134   Scan_rate=1/Period*1.E+9         ! SCAN RATE READINGS/SEC
135   Count$=VAL$(2)                   ! NUMBER OF READINGS TO TAKE- SENT TO CARD
136   !
137   !=======================================================
138 Const_6942:  !
139   !====================================================
140   Start_chn=0                                 ! START CHANNEL
141   Stop_chn=79                                 ! STOP CHANNEL
142   T1_wait=3.0                                 ! MIN TIME TO WAIT BEFORE GET DATA
143   T2_wait=3.25                                ! TIME TO WAIT BEFORE STOP SCAN
144   Npts=3125                                   ! NUMBER OF POINTS
145   Nchns=80                                    ! NUMBER OF CHANNELS SCANNED
146   Array_sze=Npts*Nchns                        ! SIZE OF DATA BUFFER
147   Mem_size=65536+196608*3                     ! SIZE OF HP6942 MEMORY
148   Pace=1/(500.0*Nchns)                        ! READINGS/SEC
149  !Pace_chn=1/(Pace*Nchns)                      ! READINGS/CHN/SEC
150   Buff_size=6.25/Pace                         ! SIX SECONDS OF DATA
151    !
152   D1$=":,704,1"                               ! DISK DRIVE TO STORE/READ DATA ON
153   D0$=":,704,0"                               ! DISK DRIVE FOR PROGRAM AND CONFIG
154   !
155    !=====================================================
156   ! PLOTTING VARIABLES"
157   !==========================================================
158   Plot_flg=1
159   I$=CHR$(129)                      ! INVERSE VIDEO ON
160   N$=CHR$(128)                      ! INVERSE VIDEO OFF
161    !
162   DATA "T","G","M","k"," ","m","u","n","p","f","a"
163   READ Unit_scale$(*)
164 !
165 ! CATALOGUE ROUTINE PLOTTING CHANNELS
166 !
167 ! FOR ICE-PROP EVENTS
168   DATA 47,61,49,55,48,50,2,10,12,19,20,26,32,34,41,45,54,56
169 !
170 ! FOR RUDDER-ICE EVENTS
171  !DATA 55,48,50,49,47,61,2,10,11,12,19,20,26,32,34,41,54,56
172   !
173 ! FOR RAMMING EVENTS
174  !DATA 2,10,19,21,34,36,38,40,41,42,43,45,46,47,49,51,54,61
175   !
176 ! FOR OPEN RUDDER ANGLE EVENTS
177 ! DATA 2,10,19,21,33,34,36,38,45,46,47,48,49,50,51,54,55,61
178   READ Cat_plot(*)
```

```
179   !
180   No_cat=18
181 !
182 !==============================================================
183 ! CONFIGURATION ARRAYS
184 !===============================================================
185 !
186   COM Id$(80)[6],Unit$(80)[8],Config$[8],Status$(80)[5]
187   COM REAL Calib(80),Offs(80),Long(80),Trans(80),Vert(80)
188   COM INTEGER Alarm(80),Fr(80)
189   COM REAL Gf(80),Excit(80),Brge(80)
190   !
191   Table_flg=1          ! FIRST TABLE
192   Chn_p=12             ! CHANNELS DISPLAYED PER PAGE-1
193   Row_o=4               ! FIRST ROW FOR CHANNEL DISCRIPTION
194   Chn1=1
195   Chn2=Nchns
196   !
197 Title_1:IMAGE 5A,2X,10A,3X,7A,6X,7A,3X,7A,1X,7A,2X,7A,2X,7A,2X,7A,3X,5A
198 Values1:IMAGE DDD,4X,10A,2X,MDDDD.DDDD,3X,MDDDDD.DD,3X,DD.DD,3X,DD.DD,4X,7A,
5X,5A
199 Values2:IMAGE DDD,4X,10A,2X,MDDD.D,3X,MDDD.D,3X,MDDD.D,5X,MDDD
200         !
201  !
202  !========================================
203  !  FILTER DESIGN VARIABLES
204  !========================================
205   COM H(201)                                  ! FILTER COEFFICIENTS
206   COM INTEGER Ft,Wt,Nf,Nh,N_st,N_end          ! WINDOW DESIGN PARAMETERS
207   COM INTEGER Pt_step                         ! TIME STEP OF FILTERED DATA
208   Read_f_flg=0
209   Pt_step=5
210  !
211    !==============================
212  ! INITIALIZATION
213    !==============================
214    !
215   !
216    !
217  ! *******************************************************************
218 Main:                  !
219  ! ********************************************************************
220              !
221   PRINTER IS 1
222   PRINT CHR$(12)
223   DUMP DEVICE IS 701
224   OFF KEY
225   ON KEY 5 LABEL "SET TIME",1 GOSUB Set_time
226   ON KEY 6 LABEL "STATS MENU",1 GOTO Stats_menu
227   ON KEY 7 LABEL "FILTER MENU",1 GOTO Filter_menu
228   ON KEY 8 LABEL "CALC VEL/AC",1 GOSUB Prox_diff
229   ON KEY 9 LABEL "HISTOGRAM",1 GOSUB Hist
230   ON KEY 0 LABEL "",1 GOTO Stay_main
231   ON KEY 1 LABEL "CONFIG CHAN",1 GOTO Config_chan
232   ON KEY 2 LABEL "",1 GOTO Stay_main
233   ON KEY 3 LABEL "6942 MENUE",1 GOTO Menue_6942
234  !ON KEY 4 LABEL "",1 GOTO STAY_MAIN
235   ON KEY 4 LABEL "",1 GOTO Stay_main
236   !
237 Stay_main:  !
```

```
238   PRINT TABXY(22,10);"M.V. KALVIK PROPULSION TESTS"
239   PRINT TABXY(25,11);"ARCTEC CANADA LIMITED"
240   PRINT TABXY(32,16);TIME$(TIMEDATE)
241   PRINT TABXY(30,15);DATE$(TIMEDATE)
242   GOTO Stay_main
243   !
244   ! **********************************************************************
245 Stats_menu: ! STATISTICAL MENU
246   ! ***********************************************************************
247             !
248   PRINTER IS 1
249   PRINT CHR$(12)
250   DUMP DEVICE IS 701
251   OFF KEY
252   ON KEY 5 LABEL "",1 GOTO Stay_stats
253   ON KEY 6 LABEL "CALC/STOR STATS",1 GOSUB Calc_stor_st
254   ON KEY 7 LABEL "PRINT STATS",1 GOTO Print_stats
255   ON KEY 8 LABEL "READ STATS",1 GOSUB Read_stats
256   ON KEY 9 LABEL "RETURN",1 GOTO Main
257   ON KEY 0 LABEL "STATS REPORT",1 GOSUB Stats_rep
258   ON KEY 1 LABEL "CALC_STATS",1 GOSUB Calc_stats
259   ON KEY 2 LABEL "STOR STATS",1 GOSUB Store_stats
260   ON KEY 3 LABEL "PLOT STATS",1 GOTO Plot_stats
261   ON KEY 4 LABEL "",1 GOTO Stay_main
262   !
263 Stay_stats: !
264   PRINT TABXY(22,10);"M.V. KALVIK PROPULSION TESTS"
265   PRINT TABXY(25,11);"ARCTEC CANADA LIMITED"
266   PRINT TABXY(32,16);TIME$(TIMEDATE)
267   PRINT TABXY(30,15);DATE$(TIMEDATE)
268   GOTO Stay_stats
269   !
270   ! **********************************************************************
271 Filter_menu:!
272   ! ***********************************************************************
273             !
274   PRINTER IS 1
275   PRINT CHR$(12)
276   DUMP DEVICE IS 701
277   OFF KEY
278   ON KEY 5 LABEL "FILTER CHANNEL",1 GOSUB Filter_6942
279   ON KEY 6 LABEL "FILTER ALL",1 GOSUB Filter_all_1
280   ON KEY 7 LABEL "GATE FILTER",1 GOSUB Gate_filter
281   ON KEY 8 LABEL "",1 GOTO Stay_filter
282   ON KEY 9 LABEL "RETURN",1 GOTO Main
283   ON KEY 0 LABEL "",1 GOTO Stay_filter
284   ON KEY 1 LABEL "",1 GOTO Stay_filter
285   ON KEY 2 LABEL "",1 GOTO Stay_filter
286   ON KEY 3 LABEL "",1 GOTO Stay_filter
287   ON KEY 4 LABEL "",1 GOTO Stay_filter
288   !
289 Stay_filter:!
290   PRINT TABXY(29,8);"FILTER MENU"
291   PRINT TABXY(22,10);"M.V. KALVIK PROPULSION TESTS"
292   PRINT TABXY(25,11);"ARCTEC CANADA LIMITED"
293   PRINT TABXY(32,16);TIME$(TIMEDATE)
294   PRINT TABXY(30,15);DATE$(TIMEDATE)
295   GOTO Stay_filter
296   !
297   !==========================================================
298 Filter_all:  !
299   !============================================================
300   Stats_flg=1
301   PRINTER IS 701
302   FOR Ev=1 TO 72
303     IF Ev>=30 THEN
304       File$="O_ICE_"&VAL$(Ev-29)
305     ELSE
306       IF (Ev)<10 THEN
307         File$="TEST_0"&VAL$(Ev)
308       ELSE
309         File$="TEST_"&VAL$(Ev)
310       END IF
311     END IF
312     !
313     GOSUB Read_tape_1
314     !
315     PRINT ""
316     PRINT "FILE$=";File$;"  EVENT$=";Event$
317     !
318     FOR Fs=1 TO 3
319       IF Fs=1 THEN
320         Chn=54
321         Gf_chn=70
322       END IF
323       IF Fs=2 THEN
324         Chn=62
325         Gf_chn=72
326       END IF
327       IF Fs=3 THEN
328         Chn=63
329         Gf_chn=73
330       END IF
331       GOSUB Gate_filter_1
332     NEXT Fs
333     GOSUB Store_tape_1
334   NEXT Ev
335   RETURN
336 Filter_all_1:    !
337     !
338     T1_f=13
339     T2_f=18
340     Pt_step=3
341     !
342   FOR Chn=58 TO 59
343     Fchn=-58+78+Chn
344     Calib(Fchn)=Calib(Chn)
345     Offs(Fchn)=Offs(Chn)
346     Unit$(Fchn)=Unit$(Chn)
347     Id$(Fchn)="f"&Id$(Chn)[1,5]
348     GOSUB Filter_6942_1
349   NEXT Chn
350   FOR Chn=45 TO 45
351     Fchn=-45+80+Chn
352     Calib(Fchn)=Calib(Chn)
353     Offs(Fchn)=Offs(Chn)
354     Unit$(Fchn)=Unit$(Chn)
355     Id$(Fchn)="f"&Id$(Chn)[1,5]
356     GOSUB Filter_6942_1
357   NEXT Chn
```

```
358   RETURN
359     !
360     !
361     RETURN
362     !
363   Chn=54
364   Fchn=70
365   GOSUB Filter_6942_1
366     !
367   FOR Chn=61 TO 63
368     Fchn=-61+71+Chn
369     GOSUB Filter_6942_1
370   NEXT Chn
371     !
372  !  GOSUB Store_tape_1
373 ! NEXT Ev
374   PRINTER IS 1
375   RETURN
376   !==========================================================
377 Plot_stats:  !
378   !==========================================================
379   !
380               !
381   Stat_flg=1
382   PRINTER IS 1
383   PRINT CHR$(12)
384   DUMP DEVICE IS 701
385   OFF KEY
386   ON KEY 5 LABEL "PLOT GRAPH",1 GOTO P_stats
387   ON KEY 6 LABEL "CHANGE_SCALES",1 GOTO Set_scale
388   ON KEY 7 LABEL "REPORT",1 GOTO Rep_stats
389   ON KEY 8 LABEL "",1 GOTO Stay_pstats
390   ON KEY 9 LABEL "RETURN",1 GOTO E_plot_stats
391   ON KEY 0 LABEL "DUMP GRAPHICS",1 GOSUB Dump_graphics
392   ON KEY 1 LABEL "LIST EVENTS",1 GOSUB List_events
393   ON KEY 2 LABEL "PRINT STATS",1 GOSUB Prt_stats
394   ON KEY 3 LABEL "",1 GOTO Stay_pstats
395   ON KEY 4 LABEL "",1 GOTO Stay_pstats
396   !
397 Stay_pstats: !
398   GOTO Stay_pstats
399   !
400 E_plot_stats:  !
401   Stat_flg=0
402   GRAPHICS OFF
403   GOTO Stats_menu
404   !
405   !=====================================================
406 List_events:  !
407   !=====================================================
408   !
409   INPUT "DO YOU WANT A HARD COPY (Y,N)",Q$
410   IF Q$="Y" THEN PRINTER IS 701
411   PRINT USING "7A,10X,10A";"EVENT #","TEST LABEL"
412   PRINT ""
413   FOR I=1 TO N_events
414     PRINT USING "DD,15X,10A";I,Catalog$(I+7)
415     IF I=45 THEN
416       PRINT CHR$(12)
417       PRINT USING "7A,10X,10A";"EVENT #","TEST LABEL"
```

```
418       PRINT ""
419     END IF
420   NEXT I
421   PRINTER IS 1
422   RETURN
423   !========================================================
424 Prt_stats: !
425   !========================================================
426   INPUT "DO YOU WAND A HARD COPY (Y/N) ?",Z$
427   IF Z$="Y" THEN PRINTER IS 701
428   FOR I=1 TO N_events
429     IF I=1 OR I=50 THEN
430       PRINT CHR$(12)
431       PRINT Title$
432       PRINT USING "/,25A,3D,4X,9A,8A,2X,5A,8A";"STATISTICS OF CHANNEL #: ",C
hn,"CHAN ID: ",Id$(Chn),"UNIT:",Unit$(Chn)
433       PRINT USING "/,5A,13X,7A,5X,7A,8X,4A,5X,7A,/";"EVENT","MAXIMUM","MINIM
UM","MEAN","ABS MAX"
434     END IF
435     Event$=Catalog$(I+7)[1,8]
436     A_max=MAX(ABS(Max_chn(I,Chn)),ABS(Min_chn(I,Chn)))
437     PRINT USING "8A,5X,4(2X,M4D.4D)";Event$,Max_chn(I,Chn),Min_chn(I,Chn),Me
an_chn(I,Chn),A_max
438   NEXT I
439   PRINTER IS 1
440   RETURN
441   !
442   !========================================================
443 Rep_stats:  !
444   !========================================================
445   INPUT "DO YOU WANT A HARD COPY (Y/N)",Hard$
446   FOR Chn=1 TO 33
447     FOR K=1 TO 2
448       S_plot$=VAL$(K)
449       GOSUB P_stats_1
450       IF Hard$="Y" THEN DUMP GRAPHICS
451     NEXT K
452     IF Hard$="Y" THEN
453       PRINTER IS 701
454       PRINT CHR$(12)
455     END IF
456   NEXT Chn
457   !
458   GOTO Plot_stats
459   !
460   !==========================================================
461 P_stats:  !
462   !==========================================================
463   INPUT "ENTER THE CHANNEL NUMBER TO PLOT MAXIMUN OF",Chn
464   INPUT "ENTER THE MAX. MIN OR MEAN (1,2,3)",S_plot$
465   !
466 P_stats_1:  !
467             !
468   Xmax=N_events
469   Xmin=0
470   IF S_plot$="1" THEN
471     Ymin=-5000
472     Ymax=15000
473   END IF
474   IF S_plot$="2" THEN
```

```
475     Ymin=-15000
476     Ymax=5000
477   END IF
478   GOSUB Stats_graph
479   GOSUB Pts_stats
480   GOTO Plot_stats
481 !
482 !===========================================================
483 Pts_stats:  !
484 !=========================================================
485   !
486     LORG 5
487   FOR I=1 TO N_events
488     IF S_plot$="1" THEN MOVE I,Max_chn(I,Chn)
489     IF S_plot$="2" THEN MOVE I,Min_chn(I,Chn)
490     IF S_plot$="3" THEN MOVE I,Mean_chn(I,Chn)
491     LABEL "+"
492   NEXT I
493   GOTO Plot_stats
494 !==========================================
495 Stats_graph:!
496 !==========================================
497 !
498   Title$="1986 M.V. KALVIK PROPULSION SYSTEM TESTS"
499   X_title$="EVENT NUMBER"
500   IF S_plot$="1" THEN Y_title$=Id$(Chn)&" MAXIMUM VALUE"
501   IF S_plot$="2" THEN Y_title$=Id$(Chn)&" MINIMUM VALUE"
502   IF S_plot$="3" THEN Y_title$=Id$(Chn)&" MEAN VALUE"
503   Y_unit$=Unit$(Chn)
504   X_unit$=""
505   GOSUB Find_scale
506   GOSUB Plot_frame
507   RETURN
508   !================================================================
509 Stats_rep:  !
510   !================================================================
511   DISP "READING ALL STATS AND SORTING ALL MIN MAX MEANS"
512   GOSUB Cat_media
513   N_events=N_files-7
514   FOR Files=8 TO N_files
515     ASSIGN @Stats TO Catalog$(Files)[1,10]&D1$
516     Event$=Catalog$(Files)[1,8]
517     GOSUB Read_stats_1
518     !
519     FOR Chn=1 TO Nchns
520       Min_chn(Files-7,Chn)=(Max_mean(1,Chn))
521       Max_chn(Files-7,Chn)=(Max_mean(2,Chn))
522       Mean_chn(Files-7,Chn)=(Max_mean(3,Chn))
523     NEXT Chn
524   !
525   NEXT Files
526   !
527   DISP ""
528   BEEP
529   RETURN
530   !=================================================================
531 Cat_media:  !
532   !=================================================================
533   !
534   MASS STORAGE IS D1$
```

```
535   CAT TO Catalog$(*):COUNT N_files
536   MASS STORAGE IS D0$
537   RETURN
538   !========================
539 Purge_media:  !
540   !=========================
541   FOR I=8 TO N_files
542     PURGE Catalog$(I)[1,10]&D1$
543   NEXT I
544   RETURN
545   !=================================================================
546 Calc_stats:  !
547   !=================================================================
548  !
549   DISP "CALCULATING STATISTICS"
550   Nchnls=80
551   Alarm_flg=0
552   Nscans=3125
553   Buff=0
554   MAT Mnmxmean= (0)
555   MAT Baseline= (0)
556   !
557   CALL Alarm_stats(Data(*),Mnmxmean(*),Mnmxptrs(*),Baseline(*),Alarm_lims(*)
,Alarm_type(*),Alarm_cnt(*),Alarm_flg,Nchnls,Nscans,Buff)
558   !
559   GOSUB Stats_filter
560   GOSUB Stats_offs
561   DISP ""
562   BEEP
563   RETURN
564   !
565   !===============================================================
566 Calc_max_min:  !
567   !===============================================================
568   FOR Chn=1 TO Nchns
569     Mnx_c(2,Chn)=Max_mean(2,Chn)
570     Mnx_c(1,Chn)=Max_mean(1,Chn)
571     FOR Ev=1 TO 72
572      !IF Status$="OK" THEN
573     !   IF Max_mean(1,Chn)<Mnx_c(1,Chn) THEN
574       !   Mnx_c(1,Chn)=Max_mean(1,Chn)
575        !  Ev_max(1,Chn)=Ev
576      !  END IF
577   !   END IF
578    !  IF Status$="OK" THEN
579     !   IF Max_mean(2,Chn)<Mnx_c(2,Chn) THEN
580         ! Mnx_c(2,Chn)=Max_mean(2,Chn)
581          !Ev_max(2,Chn)=Ev
582       ! END IF
583    !  END IF
584     NEXT Ev
585   NEXT Chn
586   RETURN
587   !========================================
588 Stats_filter:   !
589   !========================================
590   FOR Chn=64 TO 73
591     IF Chn<>71 THEN
592       Pt_step=5
593     ELSE
```

```
594       Pt_step=1
595     END IF
596     Rdg1=N_st+Pt_step*(-INT((Nh)/Pt_step)+INT(0*Pace_chn/Pt_step))
597     IF Rdg1<=0 THEN Rdg1=1
598     Max_mean(1,Chn)=Data(1,Chn)
599     Max_mean(2,Chn)=Data(1,Chn)
600     Max_mean(3,Chn)=Data(1,Chn)
601         !
602     IF Chn=71 THEN
603       Max_mean(1,71)=Offs(71)
604       Max_mean(2,71)=Offs(71)
605       Max_mean(3,71)=Offs(71)
606     END IF
607     !
608     Pts=0
609     Mean=0
610     FOR Rdg=Rdg1 TO Npts STEP Pt_step
611       IF Data(Rdg,Chn)<>5000 THEN
612         Pts=Pts+1
613     !
614         IF Data(Rdg,Chn)>Max_mean(2,Chn) THEN
615           Max_mean(2,Chn)=Data(Rdg,Chn)
616         END IF
617         IF Data(Rdg,Chn)<Max_mean(1,Chn) THEN
618           Max_mean(1,Chn)=(Data(Rdg,Chn))
619         END IF
620         Mean=Data(Rdg,Chn)+Mean
621       END IF
622     NEXT Rdg
623     IF Pts=0 THEN Pts=1
624     Max_mean(3,Chn)=Mean/Pts
625     !
626     Max_mean(1,Chn)=(Max_mean(1,Chn)-Offs(Chn))*Calib(Chn)
627     Max_mean(2,Chn)=(Max_mean(2,Chn)-Offs(Chn))*Calib(Chn)
628     Max_mean(3,Chn)=(Max_mean(3,Chn)-Offs(Chn))*Calib(Chn)
629   NEXT Chn
630   DISP ""
631   RETURN
632   !
633   !=================================================================
634 Print_stats:  !
635   !=================================================================
636   !
637   PRINT CHR$(12)
638   !
639   PRINT "EVENT: ";Event$;"     DATE/TIME:  ";DATE$(Time_acq)&" / "&TIME$(Tim
e_acq)
640   PRINT ""
641   PRINT USING "7A,8X,3A,10X,3A,10X,4A,10X,6A";"CHN. ID","MIN","MAX","MEAN","
UNITS"
642   PRINT ""
643   PRINT ""
644   FOR Chn=1 TO Nchns
645     IF Id$(Chn)[1,1]<>"" AND Status$(Chn)="OK" THEN
646   !
647       Mnmx3=(Max_mean(3,Chn))
648       Mnmx2=(Max_mean(2,Chn))
649       Mnmx1=(Max_mean(1,Chn))
650   !
651       PRINT USING "7A,5X,MDDDDD.DD,5X,MDDDDD.DD,5X,MDDDDD.DD,8X,8A";Id$(Chn)
```

```
,Mnmx1,Mnmx2,Mnmx3,Unit$(Chn)
652      END IF
653    NEXT Chn
654    !
655    DISP "PUSH CONT"
656    PAUSE
657    !
658    DISP ""
659    GOTO Stats_menu
660    !
661    !===============================================
662 Set_time:  !
663    !===============================================
664    INPUT "ENTER THE TIME (HH:MM:SS)",T_time$
665    INPUT "ENTER THE DATE (DD/MMM/YYYY)",T_date$
666    Time_sec=TIME(T_time$)
667    Time_date=DATE(T_date$)
668    SET TIMEDATE (Time_sec+Time_date)
669    RETURN
670     !
671     !=============================================
672 Init_ad:   !
673     !=============================================
674    ASSIGN @Path_ad TO Ad;WORD
675    DISP "INIT AD200"
676    RESET @Ad_buff
677    OUTPUT Ad;"reset"                         ! RESETS AND CLEARS FLAGS
678    OUTPUT Ad;"count "&Count$                 ! NUMBER OF READING TO TAKE
679    OUTPUT Ad;"time "&Period_$&" delayon" !  SET PERIOD AND DELAY ON
680    !                                          (INTERNAL TRIGGER)
681    !
682    ! SCANNING SEQUENCE:
683    !
684    OUTPUT Ad;"select 1S1 9S1 end"
685    OUTPUT Ad;"internal"                        ! INTERNAL TRIGGER
686   !
687    DISP ""
688    BEEP
689    RETURN
690    !
691    !=============================================
692 Set_scale:    !
693    !=============================================
694    INPUT "ENTER XMIN,XMAX",Xmin,Xmax
695    INPUT "ENTER YMIN,YMAX",Ymin,Ymax
696    PEN 0
697    LORG 5
698    CSIZE 5
699    IF Position<>0 THEN MOVE Position,(Data(Position,Chn)-Offs(Chn))*Calib(Chn
)
700    LABEL "+"
701    PEN 1
702    GOSUB Find_scale
703    GOSUB Plot_frame
704    PEN 2
705    IF Stat_flg=1 THEN GOTO Pts_stats
706    IF Vel_acc_flg=1 THEN GOTO Vel_acc_1
707    IF S_b_l_flg=1 THEN GOTO Pts_s_l
708    GOSUB Pts_6942
709    PEN 0
```

```
710   GOTO Plot_menue
711   !
712   !==================================================================
713 Scales:  !
714   ! ***********************************************************************
715   !
716 Find_scale:   !
717   !
718   Xscale=ABS(Xmax-Xmin)
719   Yscale=ABS(Ymax-Ymin)
720   IF Xscale=0 THEN Xscale=1.E-9
721   IF Yscale=0 THEN Yscale=1.E-9
722   !
723   Scale_mx=10^INT(LGT(Xscale))
724   Scale_my=10^INT(LGT(Yscale))
725   !
726   ! DETERMINE INDICE FOR UNIT_SCALE$
727   !
728   Unit_iy=5-(LGT(Scale_my) DIV 3)
729   Unit_ix=5-(LGT(Scale_mx) DIV 3)
730   !
731   IF LGT(Scale_my)<0 THEN
732     IF LGT(Scale_my) MOD 3<>0 THEN
733       Unit_iy=Unit_iy+1
734     END IF
735   END IF
736   IF LGT(Scale_mx)<0 THEN
737     IF LGT(Scale_mx) MOD 3<>0 THEN
738       Unit_ix=Unit_ix+1
739     END IF
740   END IF
741   !
742   IF Unit_iy<1 THEN Unit_iy=1
743   IF Unit_ix<1 THEN Unit_ix=1
744   IF Unit_iy>11 THEN Unit_iy=11
745   IF Unit_ix>11 THEN Unit_ix=11
746   !
747   DISP
748   RETURN
749   !
750   !====================================================================
751 Label_cover:  !
752   !====================================================================
753   !
754   Q$=""
755   INPUT "DO YOU WANT A COLOUR PLOT (Y,N)",Q$
756   IF Q$="Y" THEN
757     PLOTTER IS 705,"HPGL"
758     X_gdu=10*100*RATIO/16.1
759     Y_gdu=8*100/8.5
760     CSIZE 4,.45
761   ELSE
762   !
763     CSIZE 9,.35
764     PRINT CHR$(12)
765     GINIT
766     GRAPHICS ON
767     PLOTTER IS CRT,"INTERNAL"
768     X_gdu=100*MAX(1,RATIO)
769     Y_gdu=100*MAX(1,1/RATIO)
```

```
770   !
771   END IF
772   VIEWPORT 0,X_gdu,0,Y_gdu
773   LORG 5
774   !
775   CLIP OFF
776   FOR I=1 TO 1
777     PEN 2
778     MOVE X_gdu*(.5-(I-1)*.001),Y_gdu*.6
779     LABEL USING "K";"EVALUATION OF A COMMERCIAL ICEBREAKER"
780     MOVE X_gdu*(.5-(I-1)*.001),Y_gdu*.5
781     LABEL USING "K";"M.V. KALVIK"
782     PEN 4
783     MOVE X_gdu*(.5-(I-1)*.001),Y_gdu*.7
784     LABEL USING "K";"CANADIAN COAST GUARD"
785     PEN 1
786     MOVE X_gdu*(.5-(I-1)*.001),Y_gdu*.4
787     LABEL USING "K";"SEPTEMBER 1986"
788   NEXT I
789   PEN 0
790   CLIP ON
791   RETURN
792   !
793   !================================================================
794 Label_figure:  !
795   !================================================================
796   !
797   INPUT "ENTER THE FIGURE LABEL",Figure$
798   !
799   PEN 2
800   PLOTTER IS 705,"HPGL"
801   X_gdu=10*100*RATIO/20
802   Y_gdu=8*100/8.5
803   VIEWPORT .1*X_gdu,.9*X_gdu,.15*Y_gdu,.9*Y_gdu
804   WINDOW 0,106,0,100
805   CSIZE 2
806   MOVE 50,-20
807   LORG 4
808   CLIP OFF
809   LABEL USING "K";Figure$
810   CLIP ON
811   PEN 0
812   PLOTTER IS CRT,"INTERNAL"
813   PEN 1
814   RETURN
815   !
816   ! **********************************************************************
817   ! PLOT FRAME
818 Plot_frame: !
819   ! **********************************************************************
820           !
821   GINIT
822   GRAPHICS ON
823   PLOTTER IS CRT,"INTERNAL"
824   GOSUB X_grad                                 ! FIND SCALE FOR X AXIS
825   GOSUB Y_grad                                 ! FIND SCALE FOR Y AXIS
826   !
827   IF Plot_flg=1 THEN
828     OUTPUT 2 USING "#,K";CHR$(255)&"K"         !CLEARS SCREEN FOR GRAPH
829     X_gdu=100*MAX(1,RATIO)
```

```
830     Y_gdu=100*MAX(1,1/RATIO)
831     C_size=3.5
832   ELSE
833     PLOTTER IS 705,"HPGL"
834     X_gdu=10*100*RATIO/20
835     Y_gdu=8*100/8.5
836     C_size=2
837     PEN 1
838   END IF
839   !
840   VIEWPORT .1*X_gdu,.9*X_gdu,.15*Y_gdu,.9*Y_gdu
841   !
842     !
843             !
844   FOR I=1 TO 1
845     IF Circ_flg=0 THEN
846       WINDOW Xmin,Xmax,Ymin,Ymax
847       IF Polar_flg=1 THEN
848         SHOW Xmin,Xmax,Ymin,Ymax
849       END IF
850     !
851       AXES X_tick,Y_tick,Xmin,Ymin,X_major,Y_major,3
852       AXES X_tick,Y_tick,Xmin,Ymax,X_major,Y_major,3
853       AXES 1000*X_tick,Y_tick,Xmax,Ymax,X_major,Y_major,3
854       IF Plot_flg=1 THEN
855         LINE TYPE 3
856         IF Polar_flg=0 THEN GRID X_tick*X_major,Y_tick*Y_major,Xmin,Ymin,1,1
857       END IF
858     ELSE
859       IF Plot_flg=1 THEN VIEWPORT .25*Y_gdu,Y_gdu,.15*Y_gdu,.9*Y_gdu
860       IF Plot_flg=-1 THEN VIEWPORT .1*Y_gdu,.75*Y_gdu,.25*Y_gdu,.85*Y_gdu
861       SHOW Xmin,Xmax,Ymin,Ymax
862       CLIP ON
863       IF Circ_flg=0 THEN AXES X_tick,Y_tick,0,Ymin,X_major,Y_major,3
864       LINE TYPE 3
865     END IF
866   !
867   NEXT I
868   LINE TYPE 1
869   PEN 2
870   !
871   !
872   !=====================================================
873 Title_label:  !
874   !=====================================================
875   !
876   LORG 6
877   CLIP OFF
878                                                  !WRITE TITLE OF PLOT
879   CSIZE C_size
880   MOVE Xmin+(Xmax-Xmin)*.5,Ymin+1.1*(Ymax-Ymin)
881   LABEL USING "K";Title$
882   !
883   CSIZE C_size                                   ! WRITE SECOND TITLE
884   MOVE Xmin+(Xmax-Xmin)*.5,Ymin+1.05*(Ymax-Ymin)
885   LABEL USING "K";Title1$
886   !
887   IF Circ_flg=1 THEN RETURN
888   !
889   !================================================
890 Axis_title:  !
891   !========================================
892   !
893   LDIR 90                                   ! WRITE Y AXIS TITLE
894   CSIZE C_size,.6
895   IF Polar_flg=0 THEN
896     MOVE Xmin-.13*(Xmax-Xmin),(Ymin+Ymax)*.5
897   ELSE
898     MOVE Xmin-.2*(Xmax-Xmin),(Ymin+Ymax)*.5
899   END IF
900   LABEL USING "K";Y_title$&"  "&Unit_scale$(Unit_iy)&" "&Y_unit$
901   !
902   LORG 4                                    ! WRITE X AXIS TITLE
903   CSIZE C_size
904   LDIR 0
905   MOVE Xmin+(Xmax-Xmin)*.5,Ymin-.11*(Ymax-Ymin)
906   LABEL USING "K";X_title$&"  "&Unit_scale$(Unit_ix)&" "&X_unit$
907   !
908   !
909!  IF Polar_flg=1 THEN GOTO Polar_frame
910   !
911   !=====================================================================
912 Label_axis:  !
913   !=====================================================================
914   !
915   LINE TYPE 3
916   PEN 1
917   CLIP ON
918   IF SGN(Ymin*Ymax)<0 THEN
919     MOVE Xmin,0                             ! DRAWS LINES AT  0,0
920     DRAW Xmax,0
921     MOVE 0,Ymin
922     DRAW 0,Ymax
923   END IF
924   !
925   PEN 2
926   LINE TYPE 1
927   CLIP OFF
928   !
929   CSIZE C_size                    ! NUMBERS X-AXIS
930   LORG 6
931   X_exp=10^(12-(3*(Unit_ix-1)))
932   Linc=X_tick*X_major
933   FOR Ir=Xmin TO Xmax STEP Linc
934     IF ABS(Ir/X_exp)<1.E-8 AND ABS(Ir/X_exp)>-1.E-8 THEN Ir=0
935     MOVE Ir,Ymin-.02*Yscale
936     LABEL USING "K";VAL$(Ir/X_exp)
937   NEXT Ir
938    !
939                                             ! NUMBERS Y AXIS
940   LORG 8
941   CSIZE C_size,.6
942   Linc=Y_tick*Y_major
943   Y_exp=10^(12-(3*(Unit_iy-1)))
944   FOR Ir=Ymin TO Ymax STEP Linc
945     IF ABS(Ir/Y_exp)<1.E-8 AND ABS(Ir/Y_exp)>-1.E-8 THEN Ir=0
946     IF Polar_flg=0 THEN
947       MOVE Xmin-.02*Xscale,Ir
948     ELSE
949       MOVE Xmin-.05*Xscale,Ir
```

```
950     END IF
951     LABEL USING "K";VAL$(Ir/Y_exp)
952   NEXT Ir
953   !
954   CLIP ON
955   RETURN
956   !
957   !========================================================
958 Polar_frame:  !
959   !========================================================
960   CSIZE C_size                      ! NUMBERS X-AXIS
961   PEN 2
962   LORG 6
963   X_exp=10^(12-(3*(Unit_ix-1)))
964   Linc=X_tick*X_major
965   !
966   FOR Ir=0 TO Xmax STEP Linc
967     IF ABS(Ir/X_exp)<1.E-8 AND ABS(Ir/X_exp)>-1.E-8 THEN Ir=0
968     MOVE Ir,-.02*Yscale
969     LABEL USING "K";VAL$(Ir/X_exp)
970   NEXT Ir
971   FOR Ir=0 TO Xmax STEP Linc
972     IF ABS(Ir/X_exp)<1.E-8 AND ABS(Ir/X_exp)>-1.E-8 THEN Ir=0
973     MOVE -Ir,-.02*Yscale
974     LABEL USING "K";VAL$(-Ir/X_exp)
975   NEXT Ir
976    !
977                                             ! NUMBERS Y AXIS
978   LORG 8
979   CSIZE C_size,.6
980   Linc=Y_tick*Y_major
981   Y_exp=10^(12-(3*(Unit_iy-1)))
982   !
983   FOR Ir=0 TO Ymax STEP Linc
984     IF ABS(Ir/Y_exp)<1.E-8 AND ABS(Ir/Y_exp)>-1.E-8 THEN Ir=0
985     MOVE -.02*Xscale,Ir
986     LABEL USING "K";VAL$(Ir/Y_exp)
987   NEXT Ir
988   !
989   FOR Ir=0 TO Ymax STEP Linc
990     IF ABS(Ir/Y_exp)<1.E-8 AND ABS(Ir/Y_exp)>-1.E-8 THEN Ir=0
991     MOVE -.02*Xscale,-Ir
992     LABEL USING "K";VAL$(-Ir/Y_exp)
993   NEXT Ir
994   !
995   CLIP ON
996   !
997   RETURN
998   !
999   ! *******************************************************************
1000  ! X_GRAD DETERMINES SCALE  FOR X AXIS
1001  ! *******************************************************************
1002 X_grad: !
1003  Xmin=Xmin/Scale_mx
1004  Xmax=Xmax/Scale_mx
1005  Xscale=ABS(Xmax-Xmin)
1006  IF Xscale<=1 THEN
1007    X_tick=.04
1008    X_major=5
1009  ELSE
```

```
1010    IF Xscale<=2 THEN
1011      X_tick=.1
1012      X_major=4
1013    ELSE
1014      IF Xscale<=5 THEN
1015        X_tick=.1
1016        X_major=5
1017      ELSE
1018        IF Xscale<=10 THEN
1019          X_tick=.2
1020          X_major=5
1021        END IF
1022      END IF
1023    END IF
1024  END IF
1025  !Xmin=INT(Xmin/(X_tick*X_major))*Scale_mx*X_tick*X_major
1026  !Xmax=(INT(Xmax/(X_tick*X_major)))*Scale_mx*X_tick*X_major
1027  Xmin=Xmin*Scale_mx
1028  Xmax=Xmax*Scale_mx
1029  Xscale=ABS(Xmax-Xmin)
1030  X_tick=X_tick*Scale_mx
1031  RETURN
1032   !
1033  ! ************************************************************************
1034  ! Y_GRAD DETERMINES SCALE  FOR Y AXIS
1035  ! ************************************************************************
1036 Y_grad: !
1037  Ymin=Ymin/Scale_my
1038  Ymax=Ymax/Scale_my
1039  Yscale=ABS(Ymax-Ymin)
1040  IF Yscale<=1 THEN
1041    Y_tick=.04
1042    Y_major=5
1043  ELSE
1044    IF Yscale<=2 THEN
1045      Y_tick=.1
1046      Y_major=4
1047    ELSE
1048      IF Yscale<=5 THEN
1049        Y_tick=.1
1050        Y_major=5
1051      ELSE
1052        IF Yscale<=10 THEN
1053          Y_tick=.2
1054          Y_major=5
1055        END IF
1056      END IF
1057    END IF
1058  END IF
1059  !Ymin=INT(Ymin/(Y_tick*Y_major))*Scale_my*Y_tick*Y_major
1060  !ymax=(INT(Ymax/(Y_tick*Y_major)))*Scale_my*Y_tick*Y_major
1061  Ymin=Ymin*Scale_my
1062  Ymax=Ymax*Scale_my
1063  Yscale=ABS(Ymax-Ymin)
1064  Y_tick=Y_tick*Scale_my
1065  RETURN
1066   !
1067  ! ************************************************************************
1068 Move_cursor: ! MOVE CURSOR
1069  ! ************************************************************************
```

```
1070  !
1071  PEN 0
1072  LORG 5
1073  CSIZE 5
1074  IF Curs_flg THEN
1075    MOVE Position/Pace_chn,(Data(Position,Chn)-Offs(Chn))*Calib(Chn)
1076    LABEL "+"
1077  END IF
1078  Curs_flg=1
1079  Position_change=INT(KNOBX)*Pt_step
1080  Position=Position+Position_change
1081  IF Position<Rdg1 THEN Position=Rdg2
1082  IF Position>Rdg2 THEN Position=Rdg1
1083  MOVE Position/Pace_chn,(Data(Position,Chn)-Offs(Chn))*Calib(Chn)
1084  LABEL "+"
1085  PEN 1
1086  DISP I$;"        ";Position/Pace_chn;" Y ";(Data(Position,Chn)-Offs(Chn))
*Calib(Chn)
1087  RETURN
1088   !
1089  !
1090  ! ===========================================================
1091  !   DUMP GRAPHICAL OUTPUT TO PRINTER
1092  ! ===========================================================
1093 Dump_graphics:     !
1094  DUMP DEVICE IS 701
1095  DUMP GRAPHICS
1096  PRINTER IS 701
1097  FOR I=1 TO 12
1098    PRINT ""
1099  NEXT I
1100  PRINTER IS 1
1101  RETURN
1102   !
1103  ! ************************************************************************
1104  ! EXIT_GRAPHICS
1105  ! ************************************************************************
1106 Exit_graphics:    !
1107  GRAPHICS OFF
1108  PEN 0
1109  LORG 5
1110  CSIZE 5
1111  !IF Position<>0 THEN MOVE X(Position),Ad_data(Position,Chn)
1112  LABEL "+"
1113  PEN 1
1114  OFF KNOB
1115  DISP ""
1116  RETURN
1117    !
1118  ! ==================================================
1119  ! PROGRAM "DA_PROP" BY D.N. BRUCE COWPER 86/08/07
1120  !====================================================
1121  ! PROGRAM DOES THE FOLLOWING:
1122  !
1123  !       1. READS CONFIGURATION MENUES FOR THE:
1124  !                           A.  A/D CARD
1125  !                           B.  SCAN CONTROL CARD
1126  !                           C.  MEMORY CARD
1127  !       2. INITIALIZES THE CARDS
1128  !       3. ALLOWS FOR CHANGING CONFIGURATION PARAMETERS
```

```
1129  !        4. READS THE DATA SENDS IT TO THE A/D THEN TO THE MEMORY CARD
1130  !        5. SCANS THE DATA CONTINUOUSLY
1131  !        6. STORES DATA ARRAY ONTO HARD DISK IF ALARM KEY PUSHED
1132  !
1133  ! NOTES:
1134  !       A. THE FOLLOWING SUB PROGRAMS MUST BE LOADED
1135  !             1. LIBRARY_3
1136  !
1137  ! ========================================
1138 ! ************************************************************************
1139 Menue_6942: !
1140 ! ************************************************************************
1141              !
1142  OFF KNOB
1143  ON KEY 0 LABEL "PLOT MENUE",1 GOTO Plot_menue
1144  ON KEY 1 LABEL "SAVE DATA",1 GOSUB Save_6942
1145  ON KEY 2 LABEL "READ DATA",1 GOSUB Read_6942
1146  ON KEY 3 LABEL "ZER OFF",1 GOSUB Zer_off
1147  ON KEY 4 LABEL "CALC OFFSET",1 GOSUB Calc_offs
1148  ON KEY 5 LABEL "READ TAPE",1 GOSUB Read_tape
1149  ON KEY 6 LABEL "SCAN",1 GOTO Scan_6942
1150  ON KEY 7 LABEL "GET DATA",1 GOTO Get_6942
1151  ON KEY 8 LABEL "",1 GOTO Menue_6942
1152  ON KEY 9 LABEL "RETURN",1 GOTO Main
1153  !
1154  Rep_flg=0
1155 Count_6942:!
1156  IF Flg_6942=1 THEN
1157    Read_wpointer(Buffer_m,Wpt)
1158    IF Flg_mem=0 AND Wpt>500000 THEN Flg_mem=1
1159    IF Flg_mem=1 AND Wpt<500000 THEN
1160      No_mem=No_mem+1
1161      Flg_mem=0
1162    END IF
1163    IF Get_flg=1 THEN RETURN
1164 |=====================================================
1165 ! SCAN AD200 CARD
1166 |=====================================================
1167    Ad_flg=1
1168.   RESET @Ad_buff
1169  !
1170           !
1171  ! ENTER @Path_ad USING "#,W";Ad_d(*)
1172    TRANSFER @Path_ad TO @Ad_buff;WAIT
1173  !
1174    DISP USING "8A,MDDDDDD,5X,8A,MDDDDDD";"AA12A";.488*Ad_d(1)*Calib(31);"RD
Q";.488*Ad_d(2)*Calib(55)
1175 ! DISP USING "8A,MDD.DDDD,5X,8A,MDDD.DDD";"AA12A";5/2048*Ad_d(1);"RDQ";5/20
48*Ad_d(2)
1176    IF .488*Ad_d(2)*Calib(55)<-200 OR .488*Ad_d(2)*Calib(55)>200 OR .488*Ad_
d(1)*Calib(31)<-7500 OR .488*Ad_d(1)*Calib(31)>4000 THEN GOTO Get_6942
1177  !
1178  !
1179  END IF
1180  GOTO Count_6942
1181 !
1182 ! ************************************************************************
1183 Plot_menue:!
1184 ! ************************************************************************
1185              !
```

```
1186  ON KEY 0 LABEL "PLOT DATA",1 GOTO Plot_6942
1187  ON KEY 1 LABEL "PLOT PTS",1 GOTO P_pts_6942
1188  ON KEY 2 LABEL "CHANGE SCALES",1 GOTO Set_scale
1189  ON KEY 3 LABEL "CALC PLOT",1 GOTO Calc_plot
1190  ON KEY 4 LABEL "EXIT GRAPHICS ",1 GOSUB Exit_graphics
1191  ON KEY 5 LABEL "DUMP GRAPHICS",1 GOSUB Dump_graphics
1192  ON KEY 6 LABEL "PLOT CALIB",1 GOTO Plot_calib
1193  ON KEY 7 LABEL "PLOTTER ",1 GOSUB Plotter_flg
1194 ! ON KEY 8 LABEL "REPORT",1 GOTO Report
1195  ON KEY 8 LABEL "PRINT MAX RDQ",1 GOSUB Max_rdq
1196  ON KEY 9 LABEL "RETURN",1 GOTO Menue_6942
1197  !
1198  Polar_flg=0
1199  !
1200  ON KNOB .1,9 GOSUB Move_cursor
1201 Wait_plot:GOTO Wait_plot
1202  !=====================================================
1203 Calc_plot:!!
1204  !=====================================================
1205  OFF KNOB
1206  ON KEY 0 LABEL "PROX PLOT",1 GOTO Prox_plot
1207  !ON KEY 1 LABEL "LABEL COVER",1 GOSUB Label_cover
1208  ON KEY 1 LABEL "RPM",1 GOTO Plot_rpm
1209  ON KEY 2 LABEL "LABEL FIGURE",1 GOSUB Label_figure
1210  ON KEY 3 LABEL "VEL/ACC",1 GOTO Vel_acc
1211  ON KEY 4 LABEL "CHANGE SCALES",1 GOTO Set_scale
1212  ON KEY 5 LABEL "CIRC DIST",1 GOTO Plot_circ
1213  ON KEY 6 LABEL "LONG DIST",1 GOTO Plot_long
1214  ON KEY 7 LABEL "SHAFT B LOAD",1 GOTO S_b_l
1215  ON KEY 8 LABEL "EXIT GRAPHICS",1 GOSUB Exit_graphics
1216  ON KEY 9 LABEL "RETURN",1 GOTO Plot_menue
1217  !
1218 Wait_calc:GOTO Wait_calc
1219  !
1220  !================================================================
1221 Plot_rpm: !
1222  !================================================================
1223  !
1224  Y_title$="R.P.M."
1225  X_title$="TIME"
1226  Y_unit$=""
1227  X_unit$="sec."
1228  !
1229  Xmin=0
1230  Xmax=Npts/Pace_chn
1231  Ymin=100
1232  Ymax=140
1233  !
1234  Title$="1986 M.V. KALVIK PROP. TESTS - ARCTEC CANADA LTD."
1235  Title1$="EVENT "&Event$&"  DATE/TIME: "&DATE$(Time_acq)&" / "&TIME$(Time_a
cq)
1236  GOSUB Find_scale
1237  GOSUB Plot_frame
1238  LORG 5
1239  !
1240  FOR Plots=1 TO 2
1241    Rdg1=1
1242 S_r_0: !
1243    FOR Rdg=Rdg1 TO Npts
1244      IF Data(Rdg,53)>-1700 THEN
```

```
1245        T1=Rdg
1246        GOTO S_r_1
1247      END IF
1248    NEXT Rdg
1249 S_r_1:    !
1250    FOR Rdg=T1 TO Npts
1251      IF Data(Rdg,53)<-1900 THEN
1252        T11=Rdg
1253        GOTO S_r_2
1254      END IF
1255    NEXT Rdg
1256 S_r_2:          !
1257    FOR Rdg=T11 TO Npts
1258      IF Data(Rdg,53)>-1700 THEN
1259        T2=Rdg
1260        IF Plots=2 THEN
1261        IF 60/((T2-T1)/Pace_chn)>100 THEN
1262          PLOT Rdg/Pace_chn,60/((T2-T1)/Pace_chn)
1263          END IF
1264        ELSE
1265          MOVE Rdg/Pace_chn,60/((T2-T1)/Pace_chn)
1266          LABEL USING "K";"+"
1267        END IF
1268        GOTO S_r_3
1269      END IF
1270    NEXT Rdg
1271 S_r_3:          !
1272   !PRINT "T2";T2;"T11";T11;"Data";Data(Rdg,53)
1273    Rdg1=T2
1274    IF Rdg>=Npts THEN
1275      IF Plots=1 THEN
1276        GOTO Next_plots1
1277      ELSE
1278        GOTO Fin_rpm
1279      END IF
1280    ELSE
1281      GOTO S_r_0
1282    END IF
1283 Next_plots1:    !
1284  NEXT Plots
1285 Fin_rpm: !
1286  GOTO Calc_plot
1287  !========================================================
1288 S_b_l: ! SHAFT BEARING LOADS
1289  !========================================================
1290  S_b_l_flg=1
1291  INPUT "ENTER THE SHAFT LOAD TO PLOT (1,2,3)",Shaft$
1292  INPUT "VERTICAL OR TRANSVERSE LOAD (V/T/A/R)",Dir$
1293  !
1294  Xmin=0
1295  Xmax=Npts/Pace_chn
1296  Ymin=-450
1297  Ymax=450
1298  Y_unit$="kN"
1299  IF Dir$="R" THEN Y_unit$="Deg."
1300  X_unit$="Sec."
1301  X_title$="TIME"
1302  IF Shaft$="1" THEN
1303  Pt_step=5
1304    IF Dir$="V" THEN Y_title$="VERT. LOAD AFT INT. BEARING"
```

```
1305     IF Dir$="T" THEN Y_title$="TRANS. LOAD AFT INT. BEARING"
1306     IF Dir$="A" THEN Y_title$="LOAD AFT INT. BEARING"
1307     IF Dir$="R" THEN Y_title$="DIRECTION LOAD AFT INT. BEARING"
1308     Chn1=78
1309     Chn2=79
1310     R_d=.57
1311     Stat_alv=110
1312     Stat_alt=1
1313   END IF
1314   IF Shaft$="2" THEN
1315   Pt_step=5
1316     IF Dir$="V" THEN Y_title$="VERT. LOAD AFT FLY. BEARING"
1317     IF Dir$="T" THEN Y_title$="TRANS. LOAD AFT FLY. BEARING"
1318     IF Dir$="A" THEN Y_title$="LOAD AFT FLY. BEARING"
1319     IF Dir$="R" THEN Y_title$="DIRECTION LOAD AFT FLY. BEARING"
1320     Chn1=64
1321     Chn2=65
1322     R_d=.86
1323     Stat_alv=67
1324     Stat_alt=-2
1325   END IF
1326   IF Shaft$="3" THEN
1327   Pt_step=5
1328     IF Dir$="V" THEN Y_title$="VERT. LOAD FWD. FLY. BEARING"
1329     IF Dir$="T" THEN Y_title$="TRANS. LOAD FWD. FLY. BEARING"
1330     IF Dir$="A" THEN Y_title$="LOAD FWD. FLY. BEARING"
1331     IF Dir$="R" THEN Y_title$="DIRECTION LOAD FWD. FLY. BEARING"
1332     Chn1=66
1333     Chn2=67
1334     R_d=.86
1335     Stat_alv=124
1336     Stat_alt=13
1337   END IF
1338   IF Dir$="V" OR Dir$="A" THEN
1339     Ymin=-200
1340     Ymax=500
1341   END IF
1342   IF Dir$="T" THEN
1343     Ymin=-300
1344     Ymax=300
1345   END IF
1346   IF Dir$="R" THEN
1347     Ymin=-200
1348     Ymax=200
1349   END IF
1350   GOSUB Find_scale
1351   GOSUB Plot_frame
1352   GOTO Pts_s_1
1353   GOTO Calc_plot
1354   !===============================================
1355 Pts_s_1: !
1356   !===============================================
1357   Rdg1=Xmin*Pace_chn
1358   Rdg2=Xmax*Pace_chn
1359   Rdg1=N_st+Pt_step*(-INT((Nh)/Pt_step)+INT(Xmin*Pace_chn/Pt_step))
1360   IF Rdg1<=0 THEN Rdg1=1
1361   IF Rdg2>Npts THEN Rdg2=Npts
1362   FOR Rdg=Rdg1 TO Rdg2 STEP Pt_step
1363     V_1=((Data(Rdg,Chn1)-Offs(Chn1))+(Data(Rdg,Chn2)-Offs(Chn2)))*.5*Calib(C
hn1)+Stat_alv
```

```
1364    T_1=((Data(Rdg,Chn1)-Offs(Chn1))-(Data(Rdg,Chn2)-Offs(Chn2)))*.5*Calib(C
hn1)*R_d+Stat_alt
1365    IF Dir$="V" THEN PLOT Rdg/Pace_chn,V_1
1366    IF Dir$="T" THEN PLOT Rdg/Pace_chn,T_1
1367    IF Dir$="R" THEN
1368      IF V_1<>0 THEN
1369       Ang_r=ATN(ABS(T_1/V_1))
1370      IF V_1<0 AND T_1>0 THEN Ang_r=-180+Ang_r
1371      IF V_1<0 AND T_1<0 THEN Ang_r=180-Ang_r
1372      IF V_1>0 AND T_1<0 THEN Ang_r=Ang_r
1373      IF V_1>0 AND T_1>0 THEN Ang_r=-Ang_r
1374      IF V_1<>0 THEN PLOT Rdg/Pace_chn,Ang_r
1375      END IF
1376    END IF
1377    IF Dir$="A" THEN
1378      PLOT Rdg/Pace_chn,SQR(T_1^2+V_1^2)
1379    END IF
1380  NEXT Rdg
1381  GOTO Calc_plot
1382  !
1383  !==================================================
1384 Plotter_flg: !
1385  !==================================================
1386  !
1387  BEEP
1388  Plot_flg=-Plot_flg
1389  RETURN
1390  !
1391  !===================================================
1392 Plot_calib: !
1393  !===================================================
1394  !
1395  Title1$=""
1396  INPUT "ENTER THE TITLE ",Title$
1397  INPUT "ENTER X AXIS TITLE",X_title$
1398  INPUT "ENTER X AXIS UNITS",X_unit$
1399  INPUT "ENTER Y AXIS TITLE",Y_title$
1400  INPUT "ENTER Y AXIS UNITS",Y_unit$
1401  !
1402  !
1403  INPUT "ENTER THE NUMBER OF POINTS",N_calib
1404  FOR I=1 TO N_calib
1405    INPUT "ENTER X,Y",Trans(I),Vert(I)
1406  NEXT I
1407  !
1408  INPUT "ENTER XMIN,XMAX",Xmin,Xmax
1409  INPUT "ENTER YMIN,YMAX",Ymin,Ymax
1410  !
1411  GOSUB Scales
1412  GOSUB Plot_frame
1413  !
1414  MOVE Trans(1),Vert(1)
1415  FOR I=1 TO N_calib
1416    PLOT Trans(I),Vert(I),-1
1417  NEXT I
1418  !
1419  LORG 5
1420  FOR I=1 TO N_calib
1421    MOVE Trans(I),Vert(I)
1422    LABEL "+"
```

```
1423  NEXT I
1424  !
1425  GOTO Plot_menue
1426  !=====================================================
1427 Clr_flg: !
1428  !======================================================
1429  Polar_flg=0
1430  Circ_flg=0
1431  Rep_flg=0
1432  Curs_flg=0
1433  Cat_flg=0
1434  Stats_flg=0
1435  Vel_acc_flg=0
1436  S_b_l_flg=0
1437  RETURN
1438  !=========================================================
1439 Plot_circ: !
1440  !==========================================================
1441  OFF KNOB
1442  Pen$=""
1443  INPUT "DO YOU WANT TO ERASE EACH GRAPH (Y,N) ?",Pen$
1444  INPUT "ENTER THE MAXIMUM RADIUS (ustrain)",Max_r
1445  INPUT "DO YOU WANT THE FWD.-AFT, AFT-AFT, FWD.  SECTION (FA,A,FWD)",Q$
1446  INPUT "ENTER THE TIME STEP",P_step
1447  INPUT "ENTER THE WAIT TIME",T_wait
1448  P_step=P_step*Pace_chn
1449  GOSUB Clr_flg
1450  Circ_flg=1
1451  Polar_flg=1
1452  GOSUB Select_time
1453  PEN 1
1454  GOSUB Circ_graph
1455  PEN 2
1456  GOTO Circ_line
1457  PEN -1
1458  Polar_flg=0
1459  PEN 0
1460  GOTO Plot_circ
1461  !
1462  !==========================================================
1463 Circ_graph: !
1464  !==========================================================
1465  !
1466  Xmin=-Max_r
1467  Xmax=Max_r
1468  Ymin=-Max_r
1469  Ymax=Max_r
1470  Ang_rate=360/Pace_chn*2
1471  !
1472  X_title$=""
1473  Y_title$=""
1474  X_unit$=""
1475  Y_unit$=""
1476  !
1477  GOSUB Scales
1478  GOSUB Plot_frame
1479  !
1480  GRAPHICS ON
1481  LINE TYPE 1
1482  MOVE 0,0
```

```
1483  !
1484  !================================================
1485 Polygons: !
1486  !================================================
1487  !
1488  FOR I=1 TO 2
1489    POLYGON .8*Xmax
1490    POLYGON .5*Xmax
1491    POLYGON .25*Xmax
1492  NEXT I
1493  Pol_off=.5*Xmax
1494  !
1495  LORG 1
1496  MOVE 0,.8*Xmax
1497  LABEL VAL$((.8*Ymax-Pol_off))&" ustrain"
1498  MOVE 0,.5*Ymax
1499  LABEL VAL$((.5*Ymax-Pol_off))&" ustrain"
1500  MOVE 0,.25*Ymax
1501  LABEL VAL$((.25*Ymax-Pol_off))&" ustrain"
1502  !
1503  !
1504  LORG 5
1505  CSIZE C_size
1506  MOVE 0,-1*Max_r
1507  CLIP OFF
1508  IF Q$="A" THEN LABEL USING "K";"AFT STERN BEARING  LOOKING FWD."
1509  IF Q$="FA" THEN LABEL USING "K";"FWD. AFT STERN BEARING  LOOKING FWD."
1510  IF Q$="FWD" THEN LABEL USING "K";"FWD. STERN BEARING  LOOKING FWD."
1511  MOVE 0,-1.1*Max_r
1512  LABEL USING "K";"CIRCUMFERENTIAL BEARING STRAIN DISTRIBUTION"
1513  !
1514  I=0
1515  IF Plot_flg=-1 THEN
1516    FOR Rdg=Rdg1 TO Rdg2 STEP P_step
1517      I=I+1
1518      PEN I+1
1519      MOVE -1.2*Max_r,-.1*Max_r*I
1520      LABEL "--- "&VAL$(Rdg/Pace_chn)&" SEC."
1521    NEXT Rdg
1522  !
1523  END IF
1524  CLIP ON
1525  !
1526  LORG 4
1527  MOVE 1.2*Xmax,0
1528  LABEL USING "K";"STBD."
1529  MOVE 1.2*Xmin,0
1530  LABEL USING "K";"PORT"
1531  RETURN
1532  !
1533  !==========================================================
1534 Circ_line: !
1535  !==========================================================
1536  !
1537  PEN 1
1538  MOVE 0,0
1539  IF Pen$="Y" THEN
1540    Itot=2
1541  ELSE
1542    Itot=1
```

```
1543  END IF
1544  !
1545  IF Plot_flg=-1 THEN PEN 2
1546  !
1547  IF Q$="FA" THEN GOTO F_aft
1548  IF Q$="A" THEN GOTO A_aft
1549  IF Q$="FWD" THEN GOTO Fwd
1550  IF Plot_flg=-1 THEN PEN 0
1551  GOTO Calc_plot
1552  !
1553  !======================================================================
1554 A_aft: !
1555  !======================================================================
1556  Pen_n=1
1557  FOR Rdg=Rdg1 TO Rdg2 STEP P_step
1558  !
1559    IF Plot_flg=-1 THEN
1560      Pen_n=Pen_n+1
1561      PEN Pen_n
1562    END IF
1563    IF Pen$="Y" THEN PEN 0
1564    FOR I=1 TO Itot
1565      MOVE (Pol_off-(Data(Rdg,27)-Offs(27))*Calib(27))*COS(150),(Pol_off-(Da
ta(Rdg,27)-Offs(27))*Calib(27))*SIN(150)
1566      IF Status$(26)="OK" THEN PLOT (Pol_off-(Data(Rdg,26)-Offs(26))*Calib(2
6))*COS(180),(Pol_off-(Data(Rdg,26)-Offs(26))*Calib(26))*SIN(180),-1
1567      IF Status$(25)="OK" THEN PLOT (Pol_off-(Data(Rdg,25)-Offs(25))*Calib(2
5))*COS(210),(Pol_off-(Data(Rdg,25)-Offs(25))*Calib(25))*SIN(210),-1
1568      IF Status$(24)="OK" THEN PLOT (Pol_off-(Data(Rdg,24)-Offs(24))*Calib(2
4))*COS(234),(Pol_off-(Data(Rdg,24)-Offs(24))*Calib(24))*SIN(234),-1
1569      IF Status$(23)="OK" THEN PLOT (Pol_off-(Data(Rdg,23)-Offs(23))*Calib(2
3))*COS(246),(Pol_off-(Data(Rdg,23)-Offs(23))*Calib(23))*SIN(246),-1
1570      IF Status$(21)="OK" THEN PLOT (Pol_off-(Data(Rdg,21)-Offs(21))*Calib(2
1))*COS(276),(Pol_off-(Data(Rdg,21)-Offs(21))*Calib(21))*SIN(276),-1
1571      IF Status$(32)="OK" THEN PLOT (Pol_off-(Data(Rdg,32)-Offs(32))*Calib(3
2))*COS(294),(Pol_off-(Data(Rdg,32)-Offs(32))*Calib(32))*SIN(294),-1
1572      IF Status$(31)="OK" THEN PLOT (Pol_off-(Data(Rdg,31)-Offs(31))*Calib(3
1))*COS(306),(Pol_off-(Data(Rdg,31)-Offs(31))*Calib(31))*SIN(306),-1
1573      IF Status$(30)="OK" THEN PLOT (Pol_off-(Data(Rdg,30)-Offs(30))*Calib(3
0))*COS(330),(Pol_off-(Data(Rdg,30)-Offs(30))*Calib(30))*SIN(330),-1
1574      IF Status$(29)="OK" THEN PLOT (Pol_off-(Data(Rdg,29)-Offs(29))*Calib(2
9))*COS(0),(Pol_off-(Data(Rdg,29)-Offs(29))*Calib(29))*SIN(0),-1
1575      IF Status$(28)="OK" THEN PLOT (Pol_off-(Data(Rdg,28)-Offs(28))*Calib(2
8))*COS(31),(Pol_off-(Data(Rdg,28)-Offs(28))*Calib(28))*SIN(31),-1
1576  !
1577  !
1578    NEXT I
1579  !
1580    IF Plot_flg=1 THEN GOSUB Blade_rot
1581  !
1582    DISP "TIME (SEC) ";Rdg/Pace_chn
1583    WAIT T_wprox
1584  NEXT Rdg
1585  PEN -1
1586  GOTO Calc_plot
1587  !
1588  !=============================================================
1589 F_aft: !
1590  !=============================================================
1591  !
```

```
1592  Pen_n=1
1593  FOR Rdg=Rdg1 TO Rdg2 STEP P_step
1594    IF Plot_flg=-1 THEN
1595      Pen_n=Pen_n+1
1596      PEN Pen_n
1597    END IF
1598  !
1599    IF Pen$="Y" THEN PEN 0
1600    FOR I=1 TO Itot
1601      MOVE (Pol_off-(Data(Rdg,15)-Offs(15))*Calib(15))*COS(150),(Pol_off-(Da
ta(Rdg,15)-Offs(15))*Calib(15))*SIN(150)
1602      IF Status$(14)="OK" THEN PLOT (Pol_off-(Data(Rdg,14)-Offs(14))*Calib(1
4))*COS(210),(Pol_off-(Data(Rdg,14)-Offs(14))*Calib(14))*SIN(210),-1
1603      IF Status$(13)="OK" THEN PLOT (Pol_off-(Data(Rdg,13)-Offs(13))*Calib(1
3))*COS(234),(Pol_off-(Data(Rdg,13)-Offs(13))*Calib(13))*SIN(234),-1
1604      IF Status$(12)="OK" THEN PLOT (Pol_off-(Data(Rdg,12)-Offs(12))*Calib(1
2))*COS(264),(Pol_off-(Data(Rdg,12)-Offs(12))*Calib(12))*SIN(264),-1
1605      IF Status$(11)="OK" THEN PLOT (Pol_off-(Data(Rdg,11)-Offs(11))*Calib(1
1))*COS(276),(Pol_off-(Data(Rdg,11)-Offs(11))*Calib(11))*SIN(276),-1
1606      IF Status$(19)="OK" THEN PLOT (Pol_off-(Data(Rdg,19)-Offs(19))*Calib(1
9))*COS(294),(Pol_off-(Data(Rdg,19)-Offs(19))*Calib(19))*SIN(294),-1
1607      IF Status$(18)="OK" THEN PLOT (Pol_off-(Data(Rdg,18)-Offs(18))*Calib(1
8))*COS(330),(Pol_off-(Data(Rdg,18)-Offs(18))*Calib(18))*SIN(330),-1
1608      IF Status$(17)="OK" THEN PLOT (Pol_off-(Data(Rdg,17)-Offs(17))*Calib(1
7))*COS(31),(Pol_off-(Data(Rdg,17)-Offs(17))*Calib(17))*SIN(31),-1
1609      IF Status$(16)="OK" THEN PLOT (Pol_off-(Data(Rdg,16)-Offs(16))*Calib(1
6))*COS(90),(Pol_off-(Data(Rdg,16)-Offs(16))*Calib(16))*SIN(90),-1
1610  !
1611  !
1612    NEXT I
1613    IF Plot_flg=1 THEN GOSUB Blade_rot
1614    DISP "TIME (SEC) ";Rdg/Pace_chn
1615  NEXT Rdg
1616    !
1617  PEN 0
1618  GOTO Calc_plot
1619  !
1620  !=============================================================
1621 Fwd: !
1622  !=============================================================
1623  !
1624  Pen_n=1
1625  FOR Rdg=Rdg1 TO Rdg2 STEP P_step
1626    IF Plot_flg=-1 THEN
1627      Pen_n=Pen_n+1
1628      PEN Pen_n
1629    END IF
1630  !
1631    IF Pen$="Y" THEN PEN 0
1632    FOR I=1 TO Itot
1633      MOVE (Pol_off-(Data(Rdg,6)-Offs(6))*Calib(6))*COS(150),(Pol_off-(Data(
Rdg,6)-Offs(6))*Calib(6))*SIN(150)
1634      IF Status$(7)="OK" THEN PLOT (Pol_off-(Data(Rdg,7)-Offs(7))*Calib(7))*
COS(180),(Pol_off-(Data(Rdg,7)-Offs(7))*Calib(7))*SIN(180),-1
1635      IF Status$(8)="OK" THEN PLOT (Pol_off-(Data(Rdg,8)-Offs(8))*Calib(8))*
COS(210),(Pol_off-(Data(Rdg,8)-Offs(8))*Calib(8))*SIN(210),-1
1636      IF Status$(9)="OK" THEN PLOT (Pol_off-(Data(Rdg,9)-Offs(9))*Calib(9))*
COS(240),(Pol_off-(Data(Rdg,9)-Offs(9))*Calib(9))*SIN(240),-1
1637      IF Status$(1)="OK" THEN PLOT (Pol_off-(Data(Rdg,1)-Offs(1))*Calib(1))*
COS(264),(Pol_off-(Data(Rdg,1)-Offs(1))*Calib(1))*SIN(264),-1
```

```
1638      IF Status$(2)="OK" THEN PLOT (Pol_off-(Data(Rdg,2)-Offs(2))*Calib(2))*
COS(300),(Pol_off-(Data(Rdg,2)-Offs(2))*Calib(2))*SIN(300),-1
1639      IF Status$(3)="OK" THEN PLOT (Pol_off-(Data(Rdg,3)-Offs(3))*Calib(3))*
COS(330),(Pol_off-(Data(Rdg,3)-Offs(3))*Calib(3))*SIN(330),-1
1640      IF Status$(4)="OK" THEN PLOT (Pol_off-(Data(Rdg,4)-Offs(4))*Calib(4))*
COS(0),(Pol_off-(Data(Rdg,4)-Offs(4))*Calib(4))*SIN(0),-1
1641      IF Status$(5)="OK" THEN PLOT (Pol_off-(Data(Rdg,5)-Offs(5))*Calib(5))*
COS(30),(Pol_off-(Data(Rdg,5)-Offs(5))*Calib(5))*SIN(30),-1
1642  !
1643  !
1644    NEXT I
1645  ! IF Plot_flg=1 THEN GOSUB Blade_rot
1646    DISP "TIME (SEC) ";Rdg/Pace_chn
1647  NEXT Rdg
1648    !
1649  PEN 0
1650  GOTO Calc_plot
1651    !
1652  !==========================================================
1653 Select_time:!
1654  !==========================================================
1655  INPUT "ENTER THE TIME INTERVAL  (T1,T2)",T_off1,T_off2
1656  INPUT "ENTER THE TIME DELAY IN SECONDS",T_wprox
1657  Circ_plot$=""
1658  INPUT "ENTER DO YOU WANT TO PLOT CIRCLES (Y,N)",Circ_plot$
1659  Rdg1=T_off1*Pace_chn
1660  Rdg2=T_off2*Pace_chn
1661  IF Rdg1=0 THEN Rdg1=1
1662  RETURN
1663  !
1664  !==========================================================
1665 Prox_diff: !
1666  !==========================================================
1667  DISP "DIFFERENTIATING PROXIMITY PROBE READINGS"
1668  Offs(74)=0
1669  Offs(75)=0
1670  Offs(76)=0
1671  Offs(77)=0
1672  !
1673  Rdg1=1
1674  Rdg2=Npts
1675  FOR Rdg=Rdg1 TO Rdg2-1
1676    Data(Rdg,74)=Data(Rdg+1,50)-Data(Rdg,50)   !     PROXF1 VEL
1677    Data(Rdg,75)=Data(Rdg+1,51)-Data(Rdg,51)   !     PROXF2 VEL
1678  NEXT Rdg
1679  !
1680  FOR Chn=74 TO 75
1681    Pt_step=2
1682    Fchn=Chn
1683    T1_f=0
1684    T2_f=6.25
1685    GOSUB Filter_6942_1
1686  NEXT Chn
1687  Xmin=0
1688  Rdg1=N_st+Pt_step*(-INT((Nh)/Pt_step)+INT(Xmin*Pace_chn/Pt_step))
1689  !
1690  FOR Rdg=Rdg1 TO Rdg2-1 STEP Pt_step
1691    Data(Rdg,76)=Data(Rdg+Pt_step,74)-Data(Rdg,74)   !     PROXF1 ACC
1692    Data(Rdg,77)=Data(Rdg+Pt_step,75)-Data(Rdg,75)   !     PROXF2 ACC
1693  NEXT Rdg
```

```
1694  DISP ""
1695  Calib(74)=Calib(50)*Pace_chn*1.E-3
1696  Calib(75)=Calib(50)*Pace_chn*1.E-3
1697  Calib(76)=Calib(50)*Pace_chn/Pt_step*Pace_chn*1.E-3
1698  Calib(77)=Calib(50)*Pace_chn/Pt_step*Pace_chn*1.E-3
1699  Id$(74)="fF1VEL"
1700  Id$(75)="fF2VEL"
1701  Id$(76)="fF1ACC"
1702  Id$(77)="fF2ACC"
1703  Unit$(74)="m/sec"
1704  Unit$(75)="m/sec"
1705  Unit$(76)="m/sec^2"
1706  Unit$(77)="m/sec^2"
1707  BEEP
1708  RETURN
1709  !=================================================================
1710 Vel_acc: !
1711  !=================================================================
1712  GOSUB Clr_flg
1713  Vel_acc_flg=1
1714  !
1715  INPUT "ENTER THE FIRST CHANNEL TO FOR PLOT ACC/VEL/DIS",Chn
1716  INPUT "ENTER THE DIRECTION OF PLOT (V/T)",Dir$
1717  !
1718  IF Chn=76 OR Chn=77 THEN Y_title$="ACCELERATION"
1719  IF Chn=50 OR Chn=51 THEN Y_title$="DISPLACEMENT"
1720  IF Chn=74 OR Chn=75 THEN Y_title$="VELOCITY"
1721  IF Dir$="V" THEN Y_title$="VERTICAL SHAFT "&Y_title$
1722  IF Dir$="T" THEN Y_title$="TRANSVERSE SHAFT "&Y_title$
1723  !
1724  Title$="1986 M.V. KALVIK PROP. TESTS - ARCTEC CANADA LTD."
1725  Title1$="EVENT "&Event$&"  DATE/TIME: "&DATE$(Time_acq)&" / "&TIME$(Time_a
cq)
1726  X_title$="TIME"
1727  Y_unit$=Unit$(Chn)
1728  X_unit$="sec."
1729  Xmin=0
1730  Xmax=Npts/Pace_chn
1731  IF Unit$(Chn)="m/sec" THEN
1732    Ymin=-.1
1733    Ymax=.1
1734  ELSE
1735    Ymin=-10
1736    Ymax=10
1737  END IF
1738  IF Unit$(Chn)="mm" THEN
1739    Ymin=-3
1740    Ymax=3
1741  END IF
1742  !
1743  Pt_step=1
1744  IF Chn>=74 THEN Pt_step=2
1745  GOSUB Find_scale
1746  GOSUB Plot_frame
1747 Vel_acc_1: !
1748  Cos_30=COS(30)
1749  Sin_30=SIN(30)
1750  Cos_26=COS(26)
1751  Sin_26=SIN(26)
1752  Rdg1=N_st+Pt_step*(-INT((Nh)/Pt_step)+INT(Xmin*Pace_chn/Pt_step))
```

```
1753  Rdg2=Xmax*Pace_chn
1754  IF Rdg1<=0 THEN Rdg1=1
1755  Yy=Cos_30*(Data(Rdg1,Chn)-Offs(Chn))*Calib(Chn)-Sin_26*(Data(Rdg1,Chn+1)-O
ffs(Chn+1))*Calib(Chn+1)
1756  Xx=Sin_30*(Data(Rdg1,Chn)-Offs(Chn))*Calib(Chn)+Cos_26*(Data(Rdg1,Chn+1)-O
ffs(Chn+1))*Calib(Chn+1)
1757  IF Dir$="V" THEN
1758    MOVE Rdg1/Pace_chn,Yy
1759  ELSE
1760    MOVE Rdg1/Pace_chn,-Xx
1761  END IF
1762  !
1763  FOR Rdg=Rdg1 TO Rdg2 STEP Pt_step
1764    Yy=Cos_30*(Data(Rdg,Chn)-Offs(Chn))*Calib(Chn)-Sin_26*(Data(Rdg,Chn+1)-O
ffs(Chn+1))*Calib(Chn+1)
1765    Xx=Sin_30*(Data(Rdg,Chn)-Offs(Chn))*Calib(Chn)+Cos_26*(Data(Rdg,Chn+1)-O
ffs(Chn+1))*Calib(Chn+1)
1766    Xx=-Xx
1767    !
1768    IF Dir$="V" THEN
1769      PLOT Rdg/Pace_chn,Yy,-1
1770    ELSE
1771      PLOT Rdg/Pace_chn,Xx,-1
1772    END IF
1773    !
1774  NEXT Rdg
1775  GOTO Calc_plot
1776  !
1777  !=============================================================
1778 Prox_plot: !
1779  !=============================================================
1780  !
1781  GOSUB Clr_flg
1782  Polar_flg=1
1783  GOSUB Select_time
1784  GOSUB Prox_graph
1785  GOSUB Prox_pts
1786  Polar_flg=0
1787  GOTO Calc_plot
1788  !
1789  !============================================================
1790 Prox_graph: !
1791  !============================================================
1792  !
1793  INPUT "ENTER MAXIMUM RAIDUS (mm)",Max_r
1794  Xmin=-Max_r
1795  Xmax=Max_r
1796  Ymin=-Max_r
1797  Ymax=Max_r
1798  !
1799  X_title$="TRANSVERSE SHAFT MOVEMENT"
1800  Y_title$="VERTICAL SHAFT MOVEMENT"
1801  X_unit$="mm"
1802  Y_unit$="mm"
1803  !
1804  GOSUB Scales
1805  GOSUB Plot_frame
1806  IF Circ_plot$="Y" THEN
1807    Off_cl=1.35
1808    Cl_d=3.55
```

```
1809     Off_pol=0
1810   ELSE
1811     Off_cl=.3
1812     Cl_d=1.05
1813     Off_pol=0
1814   END IF
1815   !
1816   LINE TYPE 1
1817   MOVE 0,Off_pol
1818   POLYGON Cl_d    ! RADIAL CLEARANCE
1819   !
1820 !
1821   LORG 5
1822   MOVE 0,.85*Ymin
1823   LABEL USING "K";"LOOKING FORWARD"
1824   !
1825   !
1826   LORG 2
1827   MOVE COS(75)*Cl_d,SIN(75)*Cl_d+Off_pol
1828   IPLOT .2*Xmax,0,-1
1829   LABEL USING "K";" CLEARANCE"
1830   !
1831   MOVE .9*Xmax,.8*Ymin
1832!  LABEL USING "K";"PROPELLER ROTATION"
1833   MOVE .8*Xmax,.8*Ymin
1834 !POLYGON .05*Ymax
1835   RETURN
1836   !
1837   !===================================================================
1838 Prox_pts: !
1839   !===================================================================
1840   !
1841   PEN 2
1842   Xx=SIN(30)*(Data(Rdg1,50)-Offs(50))*Calib(50)+COS(26)*(Data(Rdg1,51)-Offs(
51))*Calib(51)
1843   Yy=COS(30)*(Data(Rdg1,50)-Offs(50))*Calib(50)-SIN(26)*(Data(Rdg1,51)-Offs(
51))*Calib(51)
1844   MOVE -Xx,Yy-Off_pol
1845   Cos_30=COS(30)
1846   Sin_30=SIN(30)
1847   Sin_26=SIN(26)
1848   Cos_26=COS(26)
1849   IF Q$="Y" OR Q$="" THEN
1850     IF Circ_plot$="Y" THEN PEN 0
1851   ELSE
1852     PEN 1
1853   END IF
1854   FOR Rdg=Rdg1 TO Rdg2
1855     Yy=Cos_30*(Data(Rdg,50)-Offs(50))*Calib(50)-Sin_26*(Data(Rdg,51)-Offs(51
))*Calib(51)
1856     Xx=Sin_30*(Data(Rdg,50)-Offs(50))*Calib(50)+Cos_26*(Data(Rdg,51)-Offs(51
))*Calib(51)
1857   !
1858     IF Circ_plot$="Y" THEN
1859       MOVE -Xx,Yy-Off_cl
1860       POLYGON 2.5,20
1861     ELSE
1862       PLOT -Xx,Yy-Off_cl-Cl_d
1863     END IF
1864     !
```

```
1865    WAIT T_wprox
1866    IF Circ_plot$="Y" THEN
1867      POLYGON 2.5,20
1868    END IF
1869    DISP "  TIME= ";Rdg/Pace_chn
1870   !GOSUB Blade_rot
1871  NEXT Rdg
1872  PEN 1
1873  RETURN
1874    !
1875    !=============================================================
1876 Blade_rot:   !
1877    !=============================================================
1878    !
1879  Ang_rate=360/Pace_chn*2.2
1880    !
1881  Ang=0
1882  PEN 0
1883  !
1884  MOVE .05*Ymax*COS((Rdg-Rdg1+Ang)*Ang_rate)+.8*Xmax,-.05*Ymax*SIN((Rdg-Rdg1
+Ang)*Ang_rate)+.8*Ymin
1885  PLOT .1*Ymax*COS((Rdg-Rdg1+Ang)*Ang_rate)+.8*Xmax,-.1*Ymax*SIN((Rdg-Rdg1+A
ng)*Ang_rate)+.8*Ymin,-1
1886  MOVE .05*Ymax*COS((Rdg-Rdg1+Ang)*Ang_rate)+.8*Xmax,-.05*Ymax*SIN((Rdg-Rdg1
+Ang)*Ang_rate)+.8*Ymin
1887  PLOT .1*Ymax*COS((Rdg-Rdg1+Ang)*Ang_rate)+.8*Xmax,-.1*Ymax*SIN((Rdg-Rdg1+A
ng)*Ang_rate)+.8*Ymin,-1
1888  MOVE Xx,Yy
1889  PEN 1
1890    !
1891  RETURN
1892  !
1893  !
1894  !======================================================
1895  !===============================================
1896 Calc_offs: !
1897  !===============================================
1898  !
1899  INPUT "ENTER THE TIME INTERVAL FOR OFFSET CALC (T1,T2)",T_off1,T_off2
1900 Calc_offs_1: !
1901  DISP "CALCULATING BASE LINE OFF SET"
1902  IF Pace_chn=0 THEN Pace_chn=500
1903  Rdg1=T_off1*Pace_chn
1904  Rdg2=T_off2*Pace_chn
1905  IF Rdg1=0 THEN Rdg1=1
1906  IF Rdg2=0 THEN Rdg2=Npts
1907  FOR Chn=1 TO 80
1908    Davg=0
1909    Pt_step=1
1910    IF Chn>=64 AND Chn<=Nchns THEN Pt_step=5
1911    Rdg1=N_st+Pt_step*(-INT((Nh)/Pt_step)+INT(T_off1*Pace_chn/Pt_step))
1912    IF Rdg1=0 THEN Rdg1=1
1913    FOR I=Rdg1 TO Rdg2 STEP Pt_step
1914      Davg=Davg+Data(I,Chn)
1915    NEXT I
1916    IF Chn<44 OR Chn>49 AND Chn<=69 OR Chn>77 THEN
1917      IF Chn<>53 AND Chn<>54 AND Chn<>55 AND Chn<>61 AND Chn<>62 AND Chn<>63
 AND Chn<>50 AND Chn<>51 THEN Offs(Chn)=INT(Davg/(Rdg2-Rdg1+1)*Pt_step)
1918    END IF
1919    IF Chn=45 THEN Offs(Chn)=INT(Davg/(Rdg2-Rdg1+1)*Pt_step)
```

```
1920  NEXT Chn
1921  DISP ""
1922  BEEP
1923  RETURN
1924  !
1925  !==============================================================
1926 Zer_off: !
1927  !==============================================================
1928  !
1929  DISP " ZERO OFF SETS"
1930  FOR Chn=1 TO 69
1931    IF Chn<44 OR Chn>49 THEN
1932      IF Chn<>53 AND Chn<>54 AND Chn<>55 AND Chn<>61 AND Chn<>62 AND Chn<>63
 AND Chn<>50 AND Chn<>51 THEN Offs(Chn)=0
1933    END IF
1934  NEXT Chn
1935  IF Chn=45 THEN Offs(Chn)=0
1936  DISP ""
1937  BEEP
1938  RETURN
1939  !
1940  !==============================================================
1941 Calc_rpm: !
1942  !==============================================================
1943  !
1944  Rpm_flg=1
1945  DISP "CALCULATING RPM"
1946  FOR Rdg=1 TO Npts
1947    Rpm_flg=0
1948    IF Data(Rdg,53)>-1900 THEN
1949      Rpm_flg=1
1950    END IF
1951  NEXT Rdg
1952  DISP ""
1953  RETURN
1954  !===============================================================
1955 Plot_long: !
1956  !===============================================================
1957  !
1958  !
1959  OFF KNOB
1960  GOSUB Clr_flg
1961  GOSUB Long_input
1962  GOSUB Long_graph
1963  GOSUB Long_lbl
1964  !
1965  IF Plot_flg=-1 THEN
1966    GOSUB Long_plotter
1967    PEN -1
1968  ELSE
1969    PEN 0
1970    GOTO Long_anim
1971  END IF
1972  !
1973  GOTO Calc_plot
1974  !
1975  !
1976  !----------------------------------------
1977 Long_input:!
1978  !----------------------------------------
```

```
1979  !
1980  Ymax=6000
1981  Ymin=-12000
1982 !INPUT "ENTER THE AFT STAVE NUMBER TO PLOT LONG DIST",Stave
1983  INPUT "ENTER THE FIRST TIME TO START ANIMATION",T1
1984  INPUT "ENTER THE SECOND TIME TO START ANIMATION",T2
1985  INPUT "ENTER YMIN,YMAX",Ymin,Ymax
1986  INPUT "ENTER DELAY TIME (SEC)",T_anim
1987  !
1988  Pen$=""
1989  INPUT "DO YOU WANT TO ERASE EACH GRAPH (Y,N) ?",Pen$
1990  IF Plot_flg=-1 THEN
1991    INPUT "ENTER THE TIME STEP",P_step
1992  END IF
1993  !
1994  Rdg1=T1*Pace_chn
1995  Rdg2=T2*Pace_chn
1996  IF Rdg1=0 THEN Rdg1=1
1997  !
1998  RETURN
1999  !==========================================================
2000 Long_graph: !
2001  !==========================================================
2002  Xmin=-1
2003  Xmax=11
2004  X_title$="DISTANCE"
2005  Y_title$="BEARING STRAIN"
2006  X_unit$="m"
2007  Y_unit$="ustrain"
2008  !
2009  GOSUB Scales
2010  GOSUB Plot_frame
2011  !
2012  !   59/12*.305+5.46+(67+67-18-5/8)/12*.305   DIST CALCULATIONS
2013  !
2014  RETURN
2015  !
2016  !=================================================================
2017 Long_lbl:!
2018  !=================================================================
2019  !
2020  PEN 1
2021  !
2022  MOVE 0,0
2023  RECTANGLE 1.5,.1*Ymax,EDGE
2024  MOVE 6.96,0
2025  RECTANGLE 1.5,.1*Ymax,EDGE
2026  MOVE 8.46,0
2027  RECTANGLE 1.5,.1*Ymax,EDGE
2028  !
2029  !
2030  PEN 2
2031  IF Plot_flg=-1 THEN CSIZE 1.9
2032  LORG 4
2033  MOVE .75,.7*Ymax
2034  LABEL USING "K";"FWD. BEARING"
2035  MOVE 8.46,.7*Ymax
2036  LABEL USING "K";"AFT. BEARING"
2037  !
2038 !MOVE 7.71,.7*Ymax
```

```
2039 !LABEL USING "K";"FWD. AFT."
2040 !MOVE 9.41,.7*Ymax
2041 !LABEL USING "K";"AFT. AFT."
2042  !
2043  MOVE .5*(Xmax-Xmin)+Xmin,.8*Ymin
2044  LABEL USING "K";"LONG. STERN BEARING LOAD DISTRIBUTION"
2045  MOVE .5*(Xmax-Xmin)+Xmin,.9*Ymin
2046  LABEL USING "K";"5 OCLOCK POSITION LOOKING FORWARD"
2047  RETURN
2048  !
2049  !==============================================================
2050 Long_anim: !
2051  !==============================================================
2052  !
2053  IF Plot_flg=1 AND Pen$="Y" THEN PEN 0
2054  FOR I=Rdg1 TO Rdg2
2055    FOR K=1 TO 2
2056      MOVE 0,0
2057      IF Status$(2)="OK" THEN PLOT .423,(Data(I,2)-Offs(2))*Calib(2)
2058      IF Status$(20)="OK" THEN PLOT 7.43,(Data(I,20)-Offs(20))*Calib(20)
2059      IF Status$(19)="OK" THEN PLOT 8.19,(Data(I,19)-Offs(19))*Calib(19)
2060      IF Status$(33)="OK" THEN PLOT 9.14,(Data(I,33)-Offs(33))*Calib(33)
2061      IF Status$(32)="OK" THEN PLOT 9.89,(Data(I,32)-Offs(32))*Calib(32)
2062    !
2063    NEXT K
2064    WAIT T_anim
2065    DISP "TIME ";I/Pace_chn
2066  NEXT I
2067  GOTO Long_anim
2068  GRAPHICS OFF
2069  DISP ""
2070  GOTO Calc_plot
2071  !
2072  !==============================================================
2073 Long_plotter: !
2074  !==============================================================
2075  !
2076  Pen_n=1
2077  FOR I=Rdg1 TO Rdg2 STEP P_step*Pace_chn
2078    Pen_n=Pen_n+1
2079    PEN Pen_n
2080    MOVE 0,0
2081    PLOT .423,(Data(I,2)-Offs(2))*Calib(2)
2082    PLOT 7.43,(Data(I,20)-Offs(20))*Calib(20)
2083    PLOT 8.19,(Data(I,19)-Offs(19))*Calib(19)
2084    PLOT 9.14,(Data(I,33)-Offs(33))*Calib(33)
2085    IF Status$(32)="OK" THEN PLOT 9.89,(Data(I,32)-Offs(32))*Calib(32)
2086    LORG 1
2087    MOVE 0,.2*Ymin+Ymin*.1*(Pen_n)
2088    LABEL "---  "&VAL$(I/Pace_chn)&" SEC"
2089  NEXT I
2090    !
2091  DISP ""
2092  RETURN
2093  !
2094  !====================================================
2095 P_pts_6942: !
2096  !====================================================
2097  !
2098  PEN 1
```

```
2099  INPUT "ENTER CHANNEL TO PLOT",Chn
2100  GOSUB Pts_6942
2101  GOTO Plot_menue
2102  !
2103  !===================================================
2104 Calc_stor_st:!
2105  !====================================================
2106  !
2107  GOSUB Clr_flg
2108  Stats_flg=1
2109! GOSUB Select_ev
2110  !
2111  FOR Event=16 TO 72
2112    IF Event<=43 THEN
2113      File$="O_ICE_"&VAL$(Event)
2114    END IF
2115    IF Event>43 AND Event<73 THEN
2116      IF Event-43<10 THEN
2117        File$="TEST_0"&VAL$(Event-43)
2118      ELSE
2119        File$="TEST_"&VAL$(Event-43)
2120      END IF
2121    END IF
2122  !
2123    GOSUB Read_tape_1
2124    !
2125    Gf_chn=71
2126    Chn=61
2127    Pace_chn=500
2128    IF Event>43 THEN
2129      GOSUB Gate_filter_1
2130      GOSUB Store_tape_1
2131    END IF
2132    T_off1=0
2133    T_off2=.2
2134    GOSUB Calc_offs_1
2135    GOSUB Calc_stats
2136    GOSUB Store_stats
2137    !
2138    !
2139 !  PRINTER IS 701
2140    PRINT "EVENT: ";File$;"     DATE/TIME:  ";DATE$(Time_acq)&" / "&TIME$(Ti
me_acq)
2141    PRINTER IS 1
2142  !
2143  NEXT Event
2144  !
2145  Stats_flg=0
2146  GOTO Stats_menu
2147  !
2148  !===================================================
2149 Stats_offs: !
2150  !===================================================
2151  !
2152  FOR Chn=1 TO 63
2153    Max_mean(1,Chn)=(Mnmxmean(1,Chn)-Offs(Chn))*Calib(Chn)
2154    Max_mean(2,Chn)=(Mnmxmean(2,Chn)-Offs(Chn))*Calib(Chn)
2155    Max_mean(3,Chn)=(Mnmxmean(3,Chn)-Offs(Chn))*Calib(Chn)
2156  NEXT Chn
2157  RETURN
```

```
2158  !==================================================
2159 Store_stats: !
2160  !==================================================
2161  !
2162  DISP "STORING STATS"
2163  CREATE BDAT Event$&"_S"&D1$,1,3000
2164  ASSIGN @Stats TO Event$&"_S"&D1$
2165  OUTPUT @Stats;Time_acq,Max_mean(*),Mnmxptrs(*)
2166  ASSIGN @Stats TO *
2167  BEEP
2168  DISP ""
2169  RETURN
2170  !==================================================
2171 Read_stats: !
2172  !==================================================
2173  !
2174  INPUT "ENTER THE EVENT LABEL",Event$
2175  ASSIGN @Stats TO Event$&"_S"&D1$
2176 Read_stats_1: !
2177  !
2178  DISP "READING STATS"
2179  ENTER @Stats;Time_acq,Max_mean(*),Mnmxptrs(*)
2180  ASSIGN @Stats TO *
2181  DISP ""
2182  RETURN
2183  !=================================================
2184 Report_plots: !
2185  !=================================================
2186  !
2187  GOSUB Clr_flg
2188  Cat_flg=1
2189  Rep_flg=1
2190  Xmin=0
2191  Xmax=0
2192  !
2193  GOSUB Select_ev
2194  FOR Event=1 TO N_ev
2195    File$=Event_1$(Event)
2196    GOSUB Read_tape_1
2197    T_off1=0
2198    T_off2=.2
2199    GOSUB Calc_offs_1
2200    GOSUB Plot_rep
2201  NEXT Event
2202    !
2203  GOTO Stats_menu
2204  !
2205  !=====================================================
2206 Select_ev:!
2207  !=====================================================
2208  !
2209  !
2210  FOR N_ev=1 TO 90
2211    Event_1$(N_ev)=""
2212    INPUT "ENTER THE EVENT LABEL TO ANALYSE",Event_1$(N_ev)
2213    IF Event_1$(N_ev)="" THEN GOTO End_nev
2214  NEXT N_ev
2215  !
2216 End_nev: !
2217  N_ev=N_ev-1
```

```
2218          !
2219  RETURN
2220          !
2221    !
2222    !================================================
2223 Plot_rep:   !
2224    !================================================
2225    !
2226  FOR Plots=1 TO No_cat
2227    Chn=Cat_plot(Plots)
2228  !
2229    GOSUB Plot_6942_1
2230    GOSUB Dump_graphics
2231    IF Plots MOD 3=0 THEN
2232      PRINTER IS 701
2233      PRINT CHR$(12)
2234    END IF
2235  !
2236  NEXT Plots
2237  BEEP
2238  BEEP
2239  IF Tape$<>"Y" THEN
2240    BEEP
2241    DISP "INSERT THE NEW DATA DISK AND PUSH CONT"
2242    PAUSE
2243  END IF
2244  !
2245  RETURN
2246  !
2247 !============================================================
2248 Plot_6942:!
2249 !============================================================
2250  GOSUB Clr_flg
2251  OFF KNOB
2252  !
2253  INPUT "ENTER THE CHANNEL NUMBER TO PLOT",Chn
2254  !
2255 Plot_6942_1: !
2256              !
2257  IF Event$[1,3]="RAM" THEN
2258    Pace_chn=100
2259  ELSE
2260    Pace_chn=500
2261  END IF
2262  IF Xmin-Xmax=0 OR Xmin<0 THEN
2263    Xmin=0
2264    Xmax=Npts/Pace_chn
2265  END IF
2266  !
2267  IF Id$(Chn)[1,2]="DB" THEN
2268    Ymin=-100
2269    Ymax=100
2270  END IF
2271  IF Id$(Chn)[1,2]="EF" THEN
2272    Ymin=0
2273    Ymax=70
2274  END IF
2275  !
2276  IF Id$(Chn)[1,2]="AC" THEN
2277    Ymin=-20
```

```
2278      Ymax=20
2279    END IF
2280    IF Id$(Chn)[1,2]="SP" THEN
2281      Ymin=0
2282      Ymax=10
2283    END IF
2284    IF Id$(Chn)[1,1]="F" OR Id$(Chn)[1,2]="AA" THEN
2285      Ymin=-10000
2286      Ymax=10000
2287    END IF
2288    IF Id$(Chn)[1,2]="SB" OR Id$(Chn)[1,3]="FSB" THEN
2289      Over_l(Chn)=500
2290      IF Id$(Chn)="FSB39" OR Id$(Chn)="FSB46" THEN Slope_l(Chn)=15
2291      IF Id$(Chn)="FSB36" THEN Slope_l(Chn)=5
2292      Ymin=-100
2293      Ymax=100
2294    END IF
2295    IF Id$(Chn)[1,3]="PRO" THEN
2296      Ymin=-3
2297      Ymax=3
2298    END IF
2299    IF Id$(Chn)[1,3]="ANG" THEN
2300      Ymin=-10
2301      Ymax=10
2302    END IF
2303    IF Id$(Chn)[1,3]="RDQ" THEN
2304      Ymin=-1.5
2305      Ymax=1.5
2306    END IF
2307    IF Id$(Chn)[1,3]="RDA" THEN
2308      Ymin=-40
2309      Ymax=40
2310    END IF
2311    !
2312    IF Id$(Chn)[1,4]="BR41" THEN
2313      Ymin=-400
2314      Ymax=400
2315    END IF
2316    IF Id$(Chn)[1,4]="BR50" OR Id$(Chn)[1,4]="BR55" THEN
2317      Ymin=-100
2318      Ymax=100
2319    END IF
2320    !
2321    IF Id$(Chn)[1,3]="ATQ" THEN
2322      Ymin=0
2323      Ymax=900
2324    END IF
2325    !
2326    IF Id$(Chn)="PITCH" THEN
2327      Ymin=-40
2328      Ymax=40
2329    END IF
2330    IF Id$(Chn)="THRUST" OR Id$(Chn)="FTHRUS" THEN
2331      Over_l(Chn)=3
2332      Slope_l(Chn)=.1
2333      Ymin=-2.5
2334      Ymax=2.5
2335    END IF
2336  Plot_re: !
2337    IF Unit$(Chn)="VOLTS" THEN
```

```
2338     Ymin=2
2339     Ymax=4
2340   END IF
2341   !
2342   IF Id$(Chn)="GSA" THEN
2343     Ymin=-100
2344     Ymax=100
2345   END IF
2346   IF Ymin=0 AND Ymax=0 THEN
2347     Ymin=-1000
2348     Ymax=1000
2349   END IF
2350   GOSUB Find_scale
2351   Title$="1986 M.V. KALVIK PROP. TESTS - ARCTEC CANADA LTD."
2352   Title1$="EVENT "&Event$&"  DATE/TIME: "&DATE$(Time_acq)&" / "&TIME$(Time_a
cq)
2353   Y_title$=Id$(Chn)
2354   X_title$="TIME"
2355   X_unit$=" sec."
2356   Y_unit$=Unit$(Chn)
2357   !
2358   GOSUB Scales
2359   GOSUB Plot_frame
2360   PEN 2
2361   GOSUB Pts_6942
2362   PEN 0
2363   IF Rep_flg<>1 THEN GOTO Plot_menue
2364   RETURN
2365   !
2366   !=============================================================
2367 Pts_6942: !
2368   !=============================================================
2369   IF Id$(Chn)[1,1]="f" THEN
2370     IF Chn>=74 AND Chn<=77 THEN
2371       Pt_step=5
2372     ELSE
2373       Pt_step=5
2374     END IF
2375   ELSE
2376     Pt_step=1
2377   END IF
2378   IF Chn>=70 AND Chn<=73 THEN Pt_step=1
2379   IF Chn>=64 AND Chn<=67 THEN Pt_step=5
2380   IF Chn=76 OR Chn=77 THEN Pt_step=5
2381   IF Chn=78 THEN Pt_step=3
2382   IF Chn=79 THEN Pt_step=3
2383   IF Chn=80 THEN Pt_step=3
2384   !
2385   !
2386   Rdg1=Xmin*Pace_chn
2387   Rdg2=Xmax*Pace_chn
2388   Rdg1=N_st+Pt_step*(-INT((Nh)/Pt_step)+INT(Xmin*Pace_chn/Pt_step))
2389   IF Rdg2>Npts THEN Rdg2=Npts
2390   IF Rdg1<=0 THEN Rdg1=1
2391   IF Data(Rdg1,Chn)<>5000 THEN MOVE Rdg1/Pace_chn,(Data(Rdg1,Chn)-Offs(Chn))
*Calib(Chn)
2392   !
2393   !
2394   !
2395   FOR I=Rdg1 TO Rdg2 STEP Pt_step
```

```
2396  !
2397    IF Id$(Chn)="PITCH" THEN
2398      IF Data(I,Chn)<0 THEN
2399        PLOT I/Pace_chn,Data(I,Chn)*(-26.5*.005)-.19,-1
2400      ELSE
2401        PLOT I/Pace_chn,Data(I,Chn)*(-17.0*.005)-.233,-1
2402      END IF
2403      !
2404    ELSE
2405    !
2406      IF Data(I,Chn)<>5000 THEN
2407        PLOT I/Pace_chn,(Data(I,Chn)-Offs(Chn))*Calib(Chn),-1
2408      END IF
2409    END IF
2410  NEXT I
2411  RETURN
2412  !=============================================================
2413 Gate_filter: !
2414  !=============================================================
2415  Gate_flg=1
2416  INPUT "ENTER THE CHANNEL TO GATE FILTER",Chn
2417  INPUT "ENTER THE CHANNEL TO STORE GATE FILTER DATA",Gf_chn
2418 !GOSUB Calc_stats
2419  !
2420   !
2421 Gate_filter_1:  !
2422  DISP "GATE FILTERING CHANNEL ",Chn
2423                   !
2424  IF Id$(Chn)[1,2]="TH" THEN
2425    Over_l(Chn)=3
2426    Slope_l(Chn)=.4
2427   !
2428  END IF
2429  IF Id$(Chn)[1,2]="SB" THEN
2430    Over_l(Chn)=100
2431    IF Chn=54 THEN Slope_l(Chn)=10
2432    IF Chn=62 OR Chn=63 THEN Slope_l(Chn)=5
2433  END IF
2434  IF Id$(Chn)[1,2]="BR" THEN
2435    Over_l(Chn)=600
2436     Slope_l(Chn)=100
2437  END IF
2438  Data(1,Gf_chn)=Mnmxmean(3,Chn)
2439  Data(Npts,Gf_chn)=Mnmxmean(3,Chn)
2440  !
2441        !
2442  Data(1,Gf_chn)=5000
2443  Data(Npts,Gf_chn)=5000
2444  FOR I=2 TO Npts-1
2445    Data(I,Gf_chn)=5000
2446        !
2447    IF ABS((Data(I,Chn)-Offs(Chn))*Calib(Chn))<Over_l(Chn) THEN
2448        !
2449      IF ABS((Data(I,Chn)-Data(I-1,Chn))*Calib(Chn))<Slope_l(Chn) THEN
2450        IF ABS((Data(I,Chn)-Data(I+1,Chn))*Calib(Chn))<Slope_l(Chn) THEN
2451          Data(I,Gf_chn)=Data(I,Chn)
2452        END IF
2453      END IF
2454    END IF
2455  NEXT I
```

```
2456  !
2457  DISP ""
2458  BEEP
2459  Gate_flg=0
2460  RETURN
2461 !==========================================================
2462 Max_rdq: !
2463 !==========================================================
2464  Dmax=ABS(Data(Rdg1,Chn))
2465  Im=Rdg1
2466  FOR I=Rdg1 TO Rdg2
2467    IF ABS(Data(I,Chn))>Dmax THEN
2468      Dmax=ABS(Data(I,Chn))
2469      Im=I
2470    END IF
2471  NEXT I
2472  !
2473  PRINTER IS 1
2474  INPUT "WANT A HARD COPY OUTPUT ? (Y OR N)",W$
2475  IF W$="Y" THEN PRINTER IS 701
2476  GRAPHICS OFF
2477  PRINT ""
2478  PRINT Title$
2479  PRINT Title1$
2480  PRINT
2481  PRINT USING "28A,2D.3D,3X,3A";"MAXIMUM RUDDER TORQUE AT ",Im/Pace_chn,"sec
"
2482  PRINT ""
2483  PRINT USING "5A,3X,7A,3X,8A,4X,5A,/";"CHAN#","CHAN ID","READING","UNITS"
2484  PRINT USING "3D,5X,7A,3X,M4D.3D,2X,7A,/";55,Id$(55),(Data(Im,55)-Offs(55))
*Calib(55),Unit$(55)
2485  PRINT USING "3D,5X,7A,3X,M4D.3D,2X,7A,/";48,Id$(48),(Data(Im,48)-Offs(48))
*Calib(48),Unit$(48)
2486  IF Data(Im,49)<0 THEN
2487    D49=Data(Im,49)*(-26.5*.005)-.19
2488  ELSE
2489    D49=Data(Im,49)*(-17.0*.005)-.233
2490  END IF
2491  PRINT USING "3D,5X,7A,3X,M4D.3D,2X,7A,/";49,Id$(49),D49,Unit$(49)
2492  PRINT USING "3D,5X,7A,3X,M4D.3D,2X,7A,/";47,Id$(47),(Data(Im,47)-Offs(47))
*Calib(47),Unit$(47)
2493  PRINT USING "3D,5X,7A,3X,M4D.3D,2X,7A,/";46,Id$(46),(Data(Im,46)-Offs(46))
*Calib(46),Unit$(46)
2494  Pt=5
2495  Ii=Nh+INT((Im-Nh)/Pt)*Pt
2496  PRINT USING "3D,5X,7A,3X,M4D.3D,2X,7A";71,Id$(71),(Data(Ii,71)-Offs(71))*C
alib(71),Unit$(71)
2497  PRINTER IS 1
2498  RETURN
2499 !==========================================================
2500 Scan_6942:!
2501 !=======================================================
2502  GOSUB Init_ad
2503  Flg_6942=1
2504  Configure("Menu_off","CONT_BUFF")
2505  GOSUB Config_6942
2506  GOSUB Init_6942
2507  GOSUB Set_6942
2508  GOSUB Cscan_6942
2509  GOTO Menue_6942
```

```
2510  !===========================================================
2511 Test_6942:   !
2512  !============================================================
2513  !
2514  !  The "Test_multi" statement
2515  !  below is optional.  This
2516  !  subprogram will test the 6944A
2517  !  at the specified select code and
2518  !  stop the program if the test fails.
2519  !
2520  Test_multi(Error_flag,23)
2521  RETURN
2522  !
2523  !
2524  !===============================================================
2525 Config_6942:!
2526  !================================================================
2527  !
2528  !  The "Configure" subprogram
2529  !  interactively builds a configuration
2530  !  file with information about the
2531  !  I/O functions in your system.
2532  !
2533  Configure("Menu_off","CONT_BUFF")
2534  !
2535  !  All I/O functions must be initialized
2536  !  before use either by "System_init"
2537  !  or individual "Init(Name)" statements.
2538  !
2539  RETURN
2540  !
2541  !=======================================================
2542 Init_6942: !
2543  !=======================================================
2544  DISP "SYSTEM INT"
2545  System_init
2546  BEEP
2547  WAIT 1
2548  DISP ""
2549  RETURN
2550  !
2551  !
2552  ! -------- INTERRUPT HANDLER SETUP --------
2553  !
2554  !  This section is used only if you will
2555  !  be using the computer's interrupt
2556  !  system with the 14752A software;
2557  !  otherwise it should be deleted.
2558  !
2559  !  Set up linkage for handling interrupts
2560  !  from devices on select code 29 (98633A)
2561  !  and 3478's on select code 8 (98624A).
2562  !  The subprogram "Intr_handler" is
2563  !  part of the 14752A LIBRARY.
2564  !
2565  ON INTR 23,3 CALL Intr_handler
2566  !
2567  !  Allow the interrupt system to
2568  !  respond to interrupt requests
2569  !  from the 6944A connected to
```

```
2570  !  select code 29 and the 3478A
2571  !  connected to select code 8.
2572  !
2573  Enable_sc_intr(23)
2574  !
2575  !  Define which I/O functions will be
2576  !  allowed to interrupt, and what value
2577  !  will be passed to the service routine
2578  !  to identify that function.
2579  !
2580  !
2581  ! -------- ERROR HANDLER SETUP ------------
2582  !
2583  !  These next 2 statements are used only if
2584  !  you want to handle run-time errors
2585  !  yourself; otherwise it should be deleted.
2586  !
2587  !  You define what operation should take
2588  !  place when an error occurs, and
2589  !  disable the 14752A error messages
2590  !  from being printed.
2591  !
2592  ON ERROR RECOVER Error_handler
2593  Set_error_print(0)
2594  !
2595  RETURN
2596  !
2597  ! ==================================================================
2598 Set_6942: !
2599  !====================================================================
2600  !
2601  !
2602! INPUT "ENTER THE FIRST CHANNEL TO SCAN",Start_chn
2603! INPUT "ENTER THE LAST CHANNEL TO SCAN",Stop_chn
2604 !INPUT "ENTER THE PACE PERIOD",Pace
2605  !
2606  DISP "SET_PAR"
2607  !
2608  !
2609  !   SCAN CONTROL CARD PARAMETERS
2610  Write_ref_regl(Buffer_m,Mem_size-1)
2611  Write_start_chn(Scan_con,Start_chn)
2612  Write_stop_chnl(Scan_con,Stop_chn)
2613  Set_period(Scan_con,Pace)
2614  !
2615  !   MEMORY CARD PARAMETERS
2616  Set_timeout(Buffer_m,50) ! 50 SEC. TO COMPLETE ANY COMMAND FOR MEM. CARD
2617  Write_rpointer(Buffer_m,2)    ! FIRST TWO READINGS ARE INCORRECT
2618  !
2619  BEEP
2620  DISP ""
2621  RETURN
2622  !
2623  !===============================================================
2624 Cscan_6942:!
2625  !================================================================
2626  !
2627  BEEP
2628  DISP "SAMPLING DATA AND WAITING SECONDS ";T1_wait
2629  !
```

```
2630  MAT Data= (0)
2631  Data_loc=0
2632  Write_rpointer(Buffer_m,0)
2633  Write_wpointer(Buffer_m,0)
2634  !
2635  T1=TIMEDATE
2636  Start(Scan_con)
2637  !
2638  WAIT T1_wait
2639  DISP ""
2640  RETURN
2641  !
2642  !=====================================================================
2643 Get_6942: !
2644  !========================================================================
2645  Get_flg=1
2646  DISP "WAITING SECONDS ";T2_wait
2647  WAIT T2_wait
2648  Stop(Scan_con)
2649  T2=TIMEDATE
2650  PRINT "TIME SCANING=";T2-T1
2651  !
2652  GOSUB Count_6942
2653  !
2654  DISP "GETTING DATA FROM 6942"
2655  !
2656  ! CALCULATING WHERE DATA IS IN 6942
2657  !
2658  Read_wpointer(Buffer_m,Wpt)
2659  Last_chn=((No_mem*Mem_size+Wpt+1) MOD Nchns)+1
2660  Rpoint=((Wpt+Mem_size-Buff_size-Last_chn+2)) MOD Mem_size
2661  !
2662  Write_rpointer(Buffer_m,Rpoint)
2663  Read_rpointer(Buffer_m,Rpoint)
2664  Read_dif_count(Buffer_m,Diffc)
2665  PRINT "DIFFERENCE COUNT";Diffc
2666  PRINT "READ POINTER= ";Rpoint
2667  !
2668  Input_iblock(Buffer_m,Data(*),Buff_size,Data_loc) !ENTER THE DATA TO 9836
2669  Time_acq=TIMEDATE                                 !ACQUISITION TIME
2670  !
2671  !
2672  Read_rpointer(Buffer_m,Rpoint)
2673  Read_wpointer(Buffer_m,Wpoint)
2674  Read_dif_count(Buffer_m,Diffc)
2675  !
2676! PRINT "LAST READ POINTER= ";Rpoint
2677! PRINT "LAST WRITE POINTER= ";Wpoint
2678 !PRINT "DIFFERENCE COUNT";Diffc
2679  BEEP
2680  BEEP
2681  BEEP
2682  DISP ""
2683  Flg_6942=0
2684  Get_flg=0
2685  No_mem=0
2686  Flg_mem=0
2687  !
2688  GOTO Menue_6942
2689  !
```

```
2690  !=======================================================
2691 Print_6942: !
2692  !=======================================================
2693  INPUT "ENTER THE CHANNEL TO PRINT",Chn
2694  INPUT "ENTER THE NUMBER OF POINTS TO PRINT",P_pts
2695!FOR Chn=1 TO Nchns
2696  FOR I=1 TO P_pts
2697    PRINT USING "9A,3X,DDD,3X,5A,MDD.DDD";"CHAN NO. ";Chn;"VOLTS";Data(I,Chn
)*(.005)
2698  NEXT I
2699!NEXT Chn
2700  RETURN
2701  !===============================================================
2702 Save_6942: ! SAVE DATA
2703  !==================================================================
2704  INPUT "ENTER THE FILE NAME",File$
2705  DISP "STORING DATA"
2706  ASSIGN @Path TO "DATA"&D1$
2707  ASSIGN @Path1 TO "TITLE"&D1$
2708  RESET @Buff_6942
2709  CONTROL @Buff_6942,4;Buff_size*2   ! SETS  NUMBER OF BYTES IN BUFFER
2710  TRANSFER @Buff_6942 TO @Path;WAIT
2711  OUTPUT @Path1;File$,Time_acq,Calib(*),Pace,Pace_chn
2712  ASSIGN @Path TO *
2713  ASSIGN @Path1 TO *
2714  DISP ""
2715  BEEP
2716  !
2717  RETURN
2718  !=========================================================
2719 Read_tape: !
2720  !=========================================================
2721  INPUT "ENTER THE FILE NAME",File$
2722 Read_tape_1: !
2723  Ms$=":,703,0"
2724  DISP "READING DATA"
2725  MAT Data= (0)
2726  ASSIGN @Path TO File$&Ms$
2727  IF Stats_flg<>1 THEN ASSIGN @Path1 TO File$&"T"&Ms$
2728  RESET @Buff_6942
2729  ENTER @Path;Data(*)
2730  ON ERROR GOTO Skip_enter
2731  IF Stats_flg<>1 THEN ENTER @Path1;Event$,Time_acq,Calib(*),Pace,Pace_chn
2732 Skip_enter:OFF ERROR
2733  ASSIGN @Path TO *
2734  IF Stats_flg<>1 THEN ASSIGN @Path1 TO *
2735  !
2736  Event$=File$
2737  !
2738  GOSUB Read_config
2739  DISP ""
2740  BEEP
2741  !
2742  RETURN
2743  !
2744  !=========================================================
2745 Store_tape: !
2746  !=========================================================
2747  INPUT "ENTER THE FILE NAME TO STORE DATA",File$
2748 Store_tape_1: !
```

```
2749  Dt$=":,703,0"
2750  DISP "STORING DATA"
2751  ASSIGN @Path TO File$&Dt$
2752  IF Stats_flg<>1 THEN ASSIGN @Path1 TO File$&"T"&Dt$
2753  RESET @Buff_6942
2754  OUTPUT @Path;Data(*)
2755  IF Stats_flg<>1 THEN OUTPUT @Path1;Event$,Time_acq,Calib(*),Pace,Pace_chn
2756  ASSIGN @Path TO *
2757  IF Stats_flg<>1 THEN ASSIGN @Path1 TO *
2758  !
2759  DISP ""
2760  BEEP
2761  !
2762  RETURN
2763  !
2764  !================================================================
2765 Read_6942:!
2766  !================================================================
2767  Q$=""
2768  INPUT "DO YOU WANT TO READ FROM THE TAPE",Q$
2769  IF Q$<>"Y" THEN
2770    DISP "READING DATA"
2771    MAT Data= (0)
2772    ASSIGN @Path TO "DATA"&D1$
2773    ASSIGN @Path1 TO "TITLE"&D1$
2774    RESET @Buff_6942
2775    TRANSFER @Path TO @Buff_6942;WAIT
2776    ON ERROR GOTO Skip_enter_1
2777    ENTER @Path1;Event$,Time_acq,Calib(*),Pace,Pace_chn
2778 Skip_enter_1:OFF ERROR
2779    ASSIGN @Path TO *
2780    ASSIGN @Path1 TO *
2781    GOSUB Read_config
2782  ELSE
2783    GOSUB Read_tape
2784  END IF
2785  DISP ""
2786  BEEP
2787  !
2788  RETURN
2789  !
2790  !=================================================
2791 Set_filter_chn: !
2792  !=================================================
2793  FOR Chn=36 TO 39
2794    Id$(Chn+28)="f"&Id$(Chn)
2795    IF Calib(Chn)>0 THEN
2796    Calib(Chn)=-Calib(Chn)
2797    END IF
2798    Calib(Chn+28)=Calib(Chn)
2799    Offs(Chn+28)=Offs(Chn)
2800    Unit$(Chn+28)=Unit$(Chn)
2801  NEXT Chn
2802    !
2803    FOR Chn=34 TO 35
2804    Id$(Chn+44)="f"&Id$(Chn)
2805    IF Calib(Chn)>0 THEN
2806    Calib(Chn)=-Calib(Chn)
2807    END IF
2808    Calib(Chn+44)=Calib(Chn)
```

```
2809      Offs(Chn+44)=Offs(Chn)
2810      Unit$(Chn+44)=Unit$(Chn)
2811      NEXT Chn
2812  FOR Chn=42 TO 43
2813      Id$(Chn+26)="f"&Id$(Chn)[1,5]
2814      Calib(Chn+26)=Calib(Chn)
2815      Offs(Chn+26)=Offs(Chn)
2816      Unit$(Chn+26)=Unit$(Chn)
2817  NEXT Chn
2818      !
2819  Chn=54
2820  Fchn=70
2821  Id$(Fchn)="f"&Id$(Chn)[1,5]
2822  Calib(Fchn)=Calib(Chn)
2823  Offs(Fchn)=Offs(Chn)
2824  Unit$(Fchn)=Unit$(Chn)
2825      !
2826  FOR Chn=61 TO 63
2827      Fchn=-61+71+Chn
2828      Id$(Fchn)="f"&Id$(Chn)[1,5]
2829      Calib(Fchn)=Calib(Chn)
2830      Offs(Fchn)=Offs(Chn)
2831      Unit$(Fchn)=Unit$(Chn)
2832  NEXT Chn
2833  !
2834  FOR Chn=40 TO 41
2835      Fchn=Chn+34
2836      Id$(Fchn)="f"&Id$(Chn)[1,5]
2837      Calib(Fchn)=Calib(Chn)
2838      Offs(Fchn)=Offs(Chn)
2839      Unit$(Fchn)=Unit$(Chn)
2840  NEXT Chn
2841  FOR Chn=34 TO 35
2842      Fchn=Chn+44
2843      Id$(Fchn)="f"&Id$(Chn)[1,5]
2844      Calib(Fchn)=Calib(Chn)
2845      Offs(Fchn)=Offs(Chn)
2846      Unit$(Fchn)=Unit$(Chn)
2847  NEXT Chn
2848  !
2849  Calib(70)=Calib(70)*.207
2850  Unit$(70)="MPa."
2851  Calib(72)=Calib(72)*.207
2852  Unit$(72)="MPa."
2853  Calib(73)=Calib(73)*.207
2854  Unit$(73)="MPa."
2855  !
2856  RETURN
2857  !
2858  !====================================================================
2859  ! ------- RUN-TIME ERROR HANDLER ---------
2860  !
2861  !  This section is used only if
2862  !  you want to handle run-time errors
2863  !  yourself; otherwise it should be deleted.
2864  !
2865 Error_handler:!
2866  !
2867  !  The action you wish to take when
2868  !  an error occurs gets programmed here.
```

```
2869  !
2870  PRINT "ERROR OCCURRED"
2871  PRINT ERRM$
2872  STOP
2873  !
2874  ! --------- END OF MAIN PROGRAM -----------
2875  !
2876  !
2877  !*************************************************************
2878 Config_chan: !!! PROGRAM "INPUT_DATA"  BY D.N. BRUCE COWPER JULY 23,1985
2879  !**************************************************************
2880  !
2881  ! VERSION 1.0
2882  !
2883  !PROGRAM DOES THE FOLLOWING:
2884  !
2885  !         1. READ INPUT DATA
2886  !         2. STORE INPUT DATA
2887  !         3. CHANGE INPUT DATA
2888  !         4. INSERT INPUT DATA
2889  !         5. DELETE INPUT DATA
2890  !         6. PRINT INPUT DATA TO PRINTER
2891  !
2892 !GOTO Skip_dummy
2893 Dummy_no: !
2894  Nchns=80             ! NUMBER OF CHANNELS
2895  FOR I=1 TO 33
2896   !Id$(I)=VAL$(I)&"TTTT"
2897  ! Unit$(I)="ustrain"
2898    Calib(I)=4.81
2899   !Offs(I)=-(I)
2900 !  Long(I)=-(I)
2901  ! Trans(I)=-(I)
2902  ! Vert(I)=-(I)
2903  ! Alarm(I)=-(I)
2904  ! Fr(I)=I
2905  ! Gf(I)=2.01
2906  ! Brge(I)=.25
2907  ! Excit(I)=1
2908  ! Status$(I)="OK"
2909  NEXT I
2910 Skip_dummy: !
2911  ! **************************************************************
2912  !
2913 Input_data:!
2914  ! ******************************************************
2915 !ON KEY 5 LABEL "FIRST PAGE",1 GOSUB First_page
2916  ON KEY 5 LABEL "RETURN",1 GOTO Leave_config
2917  ON KEY 6 LABEL "CHANGE",1 GOSUB Change_list
2918  ON KEY 7 LABEL "DELETE DATA",1 GOTO Delete_data
2919  ON KEY 8 LABEL "INSERT",1 GOSUB Insert_chan
2920  ON KEY 9 LABEL "NEXT CHANNEL",1 GOSUB Next_chan
2921  ON KEY 0 LABEL "FIRST PAGE",1 GOSUB First_page
2922  ON KEY 1 LABEL "NEXT PAGE ",1 GOSUB Next_page
2923! ON KEY 1 LABEL "NEXT_TABLE ",1 GOSUB Table_1_2
2924  ON KEY 2 LABEL "STORE DATA",1 GOSUB Store_config
2925  ON KEY 3 LABEL "READ DATA",1 GOSUB Read_config
2926  ON KEY 4 LABEL "PRINT DATA",1 GOSUB Print_config
2927  GOTO Input_data
2928 Leave_config:!
```

```
2929  DISP ""
2930  PRINT CHR$(12)
2931  GOTO Main
2932  !=================================================================
2933 Table_1_2: !
2934  !=================================================================
2935  Table_flg=-Table_flg
2936  GOSUB Print_table
2937  RETURN
2938  !
2939  !
2940 Delete_data:!
2941  ! *********************************************************
2942  ON KEY 5 LABEL "DELETE PAGE",1 GOSUB Del_page
2943  ON KEY 6 LABEL "DELETE SECTION",1 GOSUB Del_sec
2944  ON KEY 7 LABEL "DELETE CHAN ",1 GOSUB Delete_1chan
2945  ON KEY 8 LABEL "NEXT CHANNEL",1 GOSUB Next_chan
2946  ON KEY 9 LABEL "RETURN ",1 GOTO Return_del
2947  ON KEY 0 LABEL "",5 GOTO Delete_data
2948  ON KEY 1 LABEL "",5 GOTO Delete_data
2949  ON KEY 2 LABEL "",5 GOTO Delete_data
2950  ON KEY 3 LABEL "",5 GOTO Delete_data
2951  ON KEY 4 LABEL "",5 GOTO Delete_data
2952  GOTO Delete_data
2953 Return_del:!
2954  DISP ""
2955  GOTO Config_chan
2956  !
2957  !********************************************************
2958 Delete_1chan: !
2959  !********************************************************
2960  N_del=1
2961  GOSUB Delete_chan
2962  RETURN
2963  !
2964  !**********************************************************
2965 Del_page: !
2966  !*********************************************************
2967  N_del=Chn2-Chn1+1
2968  Chn=Chn1
2969  GOSUB Delete_chan
2970  RETURN
2971  !**********************************************************
2972 Del_sec:!
2973  INPUT "ENTER THE FIRST CHANNEL No. OF SECTION TO DELETE",Del_1
2974  INPUT "ENTER THE LAST CHANNEL No. OF SECTION TO DELETE ",Del_2
2975  N_del=Del_2-Del_1+1
2976  Chn=Del_1
2977  GOSUB Delete_chan
2978  RETURN
2979  !**********************************************************
2980  !*************************************************************
2981 First_page: !
2982  !*************************************************************
2983  Chn1=1
2984  Chn2=Chn1+Chn_p
2985  GOSUB Print_table
2986  RETURN
2987  !*************************************************************
2988 Next_page: !
```

```
2989  !************************************************************
2990  Chn1=Chn1+Chn_p+1
2991  Chn2=Chn1+Chn_p
2992  IF Chn2>Nchns AND Chn1<=Nchns THEN Chn2=Nchns
2993  IF Chn1>Nchns THEN
2994    Chn1=1
2995    Chn2=Chn1+Chn_p
2996  END IF
2997  GOSUB Print_table
2998  RETURN
2999   !
3000  !****************************************************************
3001 Print_table: !
3002  !******************************************************************
3003  IF Chn1>Nchns THEN
3004    Chn1=Nchns-Chn_p
3005    Chn2=Chn1+Chn_p
3006  END IF
3007  IF Chn2>Nchns THEN Chn2=Nchns
3008  IF Chn2-Chn1>Chn_p THEN Chn2=Chn1+Chn_p
3009  IF Chn1<1 THEN
3010    PRINT CHR$(12)
3011    DISP "NO MORE CHANNELS "
3012    BEEP
3013    RETURN
3014  END IF
3015  !
3016  PRINT CHR$(12)
3017  PRINT ""
3018  GOSUB Print_titles
3019  PRINT ""
3020  Row=Row_o
3021  FOR Chn=Chn1 TO Chn2
3022    PRINT TABXY(1,Row)
3023    GOSUB Print_values
3024    Row=Row+1
3025  NEXT Chn
3026  Row=Row_o
3027  Chn=Chn1
3028  PRINT CHR$(129)
3029  PRINT TABXY(1,Row)
3030  GOSUB Print_values
3031  PRINT CHR$(128)
3032  RETURN
3033  !
3034 !*******************************************************************
3035 Next_chan: !
3036 !*******************************************************************
3037  Chn=Row-Row_o+Chn1
3038  PRINT TABXY(1,Row-1)
3039  PRINT CHR$(128)
3040  GOSUB Print_values
3041  Row=Row+1
3042  IF Row=Chn2-Chn1+1+Row_o THEN Row=Row_o
3043  IF Chn>Nchns THEN Row=Row_o
3044  Chn=Row-Row_o+Chn1
3045  PRINT CHR$(129)
3046  PRINT TABXY(1,Row)
3047  GOSUB Print_values
3048  PRINT CHR$(128)
```

```
3049  RETURN
3050  !
3051  !=================================================================
3052 Change_list: !
3053  !=================================================================
3054  IF Table_flg=1 THEN
3055    INPUT "ENTER CHAN. ID. (10 CHARACTERS)",Id$(Chn)
3056    INPUT "ENTER CALIB. (MDDD.D)",Calib(Chn)
3057    INPUT "ENTER OFF SET (MDDD.D)",Offs(Chn)
3058    INPUT "ENTER GAUGE FACTOR  (D.DD)",Gf(Chn)
3059    INPUT "ENTER EXCITATION ",Excit(Chn)
3060    INPUT "ENTER BRIDGE CONFIGURATION (1,.75,.5,.25)",Brge(Chn)
3061    INPUT "ENTER ALARM LIMIT",Alarm(Chn)
3062    INPUT "ENTER UNITS",Unit$(Chn)
3063    INPUT "ENTER STATUS",Status$(Chn)
3064  ELSE
3065    INPUT "ENTER CHAN. ID.",Id$(Chn)
3066    INPUT "ENTER LONGITUDINAL LOCATION",Long(Chn)
3067    INPUT "ENTER TRANSVERSE LOCATION",Trans(Chn)
3068    INPUT "ENTER VERTICAL LOCATION",Vert(Chn)
3069    INPUT "ENTER FRAME LOCATION",Fr(Chn)
3070  END IF
3071  PRINT CHR$(129)
3072  PRINT TABXY(1,Row)
3073  GOSUB Print_values
3074  PRINT CHR$(128)
3075  RETURN
3076  !==============================================================
3077 Delete_chan: !
3078  !==============================================================
3079  DISP "DELETING CHANNEL PLEASE WAIT"
3080  Nchns=Nchns-N_del
3081  FOR I=Chn TO Nchns
3082    Id$(I)=Id$(I+N_del)
3083    Calib(I)=Calib(I+N_del)
3084    Offs(I)=Offs(I+N_del)
3085    Gf(I)=Gf(I+N_del)
3086    Excit(I)=Excit(I+N_del)
3087    Brge(I)=Brge(I+N_del)
3088    Alarm(I)=Alarm(I+N_del)
3089    Unit$(I)=Unit$(I+N_del)
3090    Status$(I)=Status$(I+N_del)
3091    Long(I)=Long(I+N_del)
3092    Trans(I)=Trans(I+N_del)
3093    Vert(I)=Vert(I+N_del)
3094    Fr(I)=Fr(I+N_del)
3095  NEXT I
3096  DISP ""
3097  GOSUB Print_table
3098  RETURN
3099  !=============================================================
3100 Insert_chan: !
3101  !==============================================================
3102  Nchns=Nchns+1
3103  IF Nchns>256 THEN
3104    BEEP
3105    DISP "NO MORE CHANNELS AVAILABLE"
3106    WAIT 2
3107    DISP ""
3108    Nchns=256
```

```
3109     RETURN
3110   END IF
3111   FOR I=Nchns TO Chn+1 STEP -1
3112     Id$(I)=Id$(I-1)
3113     Calib(I)=Calib(I-1)
3114     Offs(I)=Offs(I-1)
3115     Gf(I)=Gf(I-1)
3116     Excit(I)=Excit(I-1)
3117     Brge(I)=Brge(I-1)
3118     Alarm(I)=Alarm(I-1)
3119     Unit$(I)=Unit$(I-1)
3120     Status$(I)=Status$(I-1)
3121     Long(I)=Long(I-1)
3122     Trans(I)=Trans(I-1)
3123     Vert(I)=Vert(I-1)
3124     Fr(I)=Fr(I-1)
3125   NEXT I
3126   INPUT "ENTER CHAN. ID. (10 CHARACTERS)",Id$(Chn)
3127   INPUT "ENTER CALIB. (MDDD.D)",Calib(Chn)
3128   INPUT "ENTER OFF SET (MDDD.D)",Offs(Chn)
3129   INPUT "ENTER GAUGE FACTOR  (D.DD)",Gf(Chn)
3130   INPUT "ENTER EXCITATION ",Excit(Chn)
3131   INPUT "ENTER BRIDGE CONFIGURATION (1,.75,.5,.25)",Brge(Chn)
3132   INPUT "ENTER ALARM LIMIT",Alarm(Chn)
3133   INPUT "ENTER UNITS",Unit$(Chn)
3134   INPUT "ENTER STATUS",Status$(Chn)
3135   INPUT "ENTER LONGITUDINAL LOCATION",Long(Chn)
3136   INPUT "ENTER TRANSVERSE LOCATION",Trans(Chn)
3137   INPUT "ENTER VERTICAL LOCATION",Vert(Chn)
3138   INPUT "ENTER FRAME LOCATION",Fr(Chn)
3139   Chn2=Chn2+1
3140   GOSUB Print_table
3141   GOSUB Next_chan
3142   RETURN
3143   !
3144   !***********************************************
3145 Store_config:!
3146   !***********************************************
3147   INPUT "ENTER THE FILE NAME (MAXIMUNM OF 10 CHARACTERS",File$
3148   DISP "CREATING FILE AND STORING ON DISC"
3149   File$=File$
3150   Bytes=80*8*8+80*2*2+8+10*80+4*80+6*80+4*80+80*5
3151   Records=INT(Bytes/256)+1
3152   CREATE BDAT File$,Records,256
3153   ASSIGN @Path TO File$
3154   OUTPUT @Path;Nchns,Calib(*),Offs(*),Long(*),Trans(*),Vert(*),Alarm(*),Fr(*
),Id$(*),Unit$(*),Gf(*),Excit(*),Brge(*),Status$(*)
3155   DISP ""
3156   ASSIGN @Path TO *
3157   RETURN
3158   !***********************************************
3159 Read_config: !
3160   !***********************************************
3161   !
3162   IF Event$[1,1]="" OR Event$[1,4]="STOP" THEN
3163     INPUT "ENTER THE FILE NAME (MAXIMUNM OF 6 CHARACTERS",Config$
3164   END IF
3165   IF Event$[1,1]="B" THEN Config$="PROP_6"
3166   IF Event$[1,1]="R" THEN Config$="PROP_6"
3167   IF Event$[1,4]="OPEN" THEN
```

```
3168    IF VAL(Event$[6,7])<=2 THEN Config$="PROP_1"
3169    IF VAL(Event$[6,7])>2 THEN Config$="PROP_2"
3170  END IF
3171  IF Event$[1,4]="TEST" THEN
3172    IF VAL(Event$[6,7])<=15 THEN Config$="PROP_4"
3173    IF VAL(Event$[6,7])>=16 AND VAL(Event$[6,7])<=19 THEN Config$="PROP_5"
3174    IF VAL(Event$[6,7])>=20 THEN Config$="PROP_6"
3175  END IF
3176    !
3177  IF Event$[1,2]="O_" THEN
3178    IF VAL(Event$[7,8])<=14 THEN
3179      Config$="PROP_1"
3180    ELSE
3181      IF VAL(Event$[7,8])>=15 AND VAL(Event$[7,8])<=26 THEN Config$="PROP_2"
3182      IF VAL(Event$[7,8])>=27 AND VAL(Event$[7,8])<=42 THEN Config$="PROP_3"
3183      IF VAL(Event$[7,8])=43 THEN Config$="PROP_4"
3184    END IF
3185  END IF
3186    !
3187  !
3188  !
3189  DISP "READING CHANNEL CONFIGURATION FILE"
3190  ASSIGN @Path TO Config$&D0$
3191  ENTER @Path;Nchns,Calib(*),Offs(*),Long(*),Trans(*),Vert(*),Alarm(*),Fr(*)
,Id$(*),Unit$(*),Gf(*),Excit(*),Brge(*),Status$(*)
3192  ASSIGN @Path TO *
3193  GOSUB Set_filter_chn
3194  DISP ""
3195  RETURN
3196  !
3197  !*************************************************************
3198 Print_config:!
3199  !*************************************************************
3200  PRINTER IS 701
3201  Chn_pp=40
3202  Chn1=1
3203  Chn2=41
3204  Npages=INT(Nchns/40)
3205  IF Nchns MOD 40>0 THEN Npages=Npages+1
3206  FOR Page=1 TO Npages
3207    PRINT " 1986 M.V. KALVIK PROPULSION TESTS - 2452 ARCTEC CANADA LTD."
3208    PRINT ""
3209    PRINT " DATE/TIME: ";DATE$(TIMEDATE)&"/"&TIME$(TIMEDATE)
3210    PRINT ""
3211    PRINT "CONFIGURATION FILE: ";Config$
3212    !
3213    IF Config$="PROP_1" THEN PRINT "FOR EVENTS O_ICE_1 TO O_ICE_14"
3214    IF Config$="PROP_2" THEN PRINT "FOR EVENTS O_ICE_15 TO O_ICE_26"
3215    IF Config$="PROP_3" THEN PRINT "FOR EVENTS O_ICE_27 TO O_ICE_42"
3216    IF Config$="PROP_4" THEN PRINT "FOR EVENTS O_ICE_43 TO TEST_15"
3217    IF Config$="PROP_5" THEN PRINT "FOR EVENTS TEST_16 TO TEST_19"
3218    IF Config$="PROP_6" THEN PRINT "FOR EVENTS TEST_20 TO TEST_29"
3219    PRINT ""
3220    GOSUB Print_titles
3221    PRINT ""
3222    FOR Chn=Chn1 TO Chn2
3223      IF Id$(Chn)="" THEN GOTO Next_chn_c
3224      GOSUB Print_values
3225 Next_chn_c:        !
3226    NEXT Chn
```

```
3227    PRINT CHR$(12)
3228    Chn1=Chn1+Chn_pp+1
3229    Chn2=Chn1+Chn_pp
3230    IF Chn2>Nchns THEN Chn2=Nchns
3231  NEXT Page
3232  PRINTER IS 1
3233  RETURN
3234  !========================================================
3235 Print_titles: !
3236  !=========================================================
3237  IF Table_flg=1 THEN
3238    PRINT "                            SENSOR SPECIFICATIONS"
3239    PRINT USING Title_1;"CHAN#","CHAN ID"," CALIB ","OFFSET","EXIT. ","BRIDG
E","UNITS","STATUS"
3240  ELSE
3241    PRINT "                            SENSOR LOCATIONS"
3242    PRINT USING Title_1;"CHAN#","CHAN ID","  LONG"," TRANS","  VERT","  FRAM
E"
3243  END IF
3244  !
3245  RETURN
3246  !
3247  !=========================================================
3248 Print_values: !
3249  !=========================================================
3250  IF Table_flg=1 THEN
3251    PRINT USING Values1;Chn,Id$(Chn),Calib(Chn),Offs(Chn),Excit(Chn),Brge(Ch
n),Unit$(Chn),Status$(Chn)
3252  ELSE
3253    PRINT USING Values2;Chn,Id$(Chn),Long(Chn),Trans(Chn),Vert(Chn),Fr(Chn)
3254  END IF
3255  RETURN
3256    !
3257  !
3258  !================================================================
3259 Filter_6942:  !
3260  !================================================================
3261  IF Read_f_flg=0 THEN GOSUB Read_filter
3262  !
3263  Pt_step=5
3264 Apply:  ! FILTER DATA
3265  INPUT "ENTER THE START AND FINISH TIME T1,T2",T1_f,T2_f
3266  INPUT "ENTER POINT STEP",Pt_step
3267  Ans$="N"
3268  INPUT "DATA CHANNEL TO BE FILTERED ?",Chn
3269 Apple:INPUT "CHANNEL # IN WHICH FILTERED DATA TO BE STORED ? (64 - 80)",Fch
n
3270  PRINT "Filter data channel # ";Chn;" and store results in channel # ";Fchn
;" ."
3271  PRINT
3272  INPUT "Make change ? (Y OR N) ",Ans$
3273  IF Ans$="Y" THEN Apply
3274  !
3275 Filter_6942_1: !
3276                   !
3277  DISP "FILTERING CHANNEL # ";Chn;" ..........Please wait"
3278  T1=TIMEDATE
3279  !
3280  Rdg1=N_st+T1_f*Pace_chn
3281  Rdg2=-(3125-N_end)+T2_f*Pace_chn
```

```
3282  !
3283! FOR M=N_st TO N_end STEP Pt_step
3284  FOR M=Rdg1 TO Rdg2 STEP Pt_step
3285    DISP M
3286    Zum=H(1)*Data(M,Chn)
3287    FOR L=2 TO Nh
3288      Zum=Zum+H(L)*(Data(M+L-1,Chn)+Data(M-L+1,Chn))
3289    NEXT L
3290    Data(M,Fchn)=Zum
3291  NEXT M
3292  !
3293  GOSUB Filter_fix
3294  !
3295  T2=TIMEDATE
3296  PRINT "CHANNEL # ";Chn;" FILTERING DONE........."
3297  PRINT "TIME TO FILTER DATA= ";T2-T1
3298  DISP ""
3299  PRINT CHR$(12)
3300  BEEP
3301  RETURN
3302  !
3303  !==============================================
3304 Filter_fix:  !
3305  !==============================================
3306  ! Fix data points between 1 and (N_ST-1) & between (N_end-1) and Npts
3307  !
3308  FOR I=1 TO 2
3309    IF I=1 THEN
3310      N1=1
3311      N2=N_st-1
3312    ELSE
3313      N1=N_end-1
3314      N2=Npts
3315    END IF
3316    !
3317    FOR M=N1 TO N2
3318      Zum=H(1)*Data(M,Chn)
3319      FOR L=2 TO Nh
3320        J=M+L-1
3321        K=M-L+1
3322        IF I=1 THEN
3323          IF K<1 THEN K=J
3324        ELSE
3325          IF J>Npts THEN J=K
3326        END IF
3327        Zum=Zum+(H(L)*(Data(J,Chn)+Data(K,Chn)))
3328      NEXT L
3329      Data(M,Fchn)=Zum
3330    NEXT M
3331    !
3332  NEXT I
3333  !
3334  RETURN
3335  !
3336  !==============================================
3337 Read_filter:  !
3338  !==============================================
3339  ! Read in filter design parameters and half filter design coefficients.
3340  !
3341  INPUT "FILE NAME OF FILTER DESIGN (4 CHAR.) ?",Fil$
```

```
3342  IF LEN(Fil$)=0 OR LEN(Fil$)>5 THEN GOTO 3341
3343  Fil1$=Fil$&"_para"&D1$
3344  Fil2$=Fil$&"_coef"&D1$
3345  ASSIGN @Road TO Fil1$
3346  ENTER @Road;Ft,Wt,Nf,Nh,Cf1,Cf2,Par1,Par2
3347  ASSIGN @Road TO *
3348  !
3349  REDIM H(Nh)
3350  ASSIGN @Ave TO Fil2$
3351  ENTER @Ave,1;H(*)
3352  ASSIGN @Ave TO *
3353  !
3354  N_st=Nh
3355  N_end=Npts-Nh+1
3356  Read_f_flg=Read_f_flg+1
3357  !
3358  RETURN
3359  !
3360 !=============
3361 Hist:                        !
3362 !=============
3363  !
3364  Title$="HISTOGRAM OF MAXIMUM TORQUE"
3365  Y_title$="NUMBER OF EVENTS"
3366  X_title$="PEAK TORQUE (MN)"
3367  X_unit$=""
3368  Y_unit$=""
3369  Ymin=0
3370  Ymax=29
3371  Xmin=0
3372  Xmax=1000
3373  Chn=47
3374  Ev_1=44
3375  Ev_2=72
3376  GOSUB Find_scale
3377  GOSUB Plot_frame
3378  CLIP OFF
3379  LORG 5
3380  PEN 3
3381  FOR K=1 TO 10
3382    Hght=0
3383    FOR I=Ev_1 TO Ev_2
3384      IF Max_chn(I,Chn)<K*Xmax/10 AND Max_chn(I,Chn)>(K-1)*Xmax/10 THEN
3385        Hght=Hght+1
3386      END IF
3387    NEXT I
3388    MOVE Xmax/10*(K-1),0
3389    RECTANGLE Xmax/10,Hght,EDGE
3390  NEXT K
3391  RETURN
3392                                !
3393                               END
3394  CSUB Alarm_stats(INTEGER Data(*),Mnmxmean(*),Mnmxptrs(*),Baseline(*),Alarm
_lims(*),Alarm_type(*),Alarm_cnt(*),Alarm_flg,Nchnls,Nscans,Buff)
```

APPENDIX G

Description of Data Products

LIST OF DATA PRODUCTS

Quantity	Description
1	Magnetic Tape Containing All Data (Two backup copies available)
1	Computer Disk Containing All Programs
1	Computer Disk Containing the Calculated Minimum, Maximum, and Mean Values of Data Collected
1	Final Report (Volume 1)
1	Appendix Material (Volume 2)